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PLANT DISEASE TRAINING MANUAL

STATE OF MONTANA
DEPARTMENT OF AGRICULTURE
HELENA, MONTANA
JANUARY, 1981

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PREFACE

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This manual was prepared as a study guide for commercial applicators engaged in plant disease control, fungicide application and seed treatment. Part I gives general information on plant diseases and fungicide application as well as other control methods for plant diseases. Part II is primarily reference material concerning common plant diseases found in Montana agricultural crops and the most effective control methods. This manual should be used for study for the Ag Plant Pest examination and the Seed Treatment examination.

To simplify information, trade named products and equipment have been mentioned. No endorsement is intended, nor is criticism implied of similar products or equipment which are not mentioned.

We wish to acknowledge the help of the following: The Montana Cooperative Extension Service, the Montana State University Plant Pathology Department and personnel of the Environmental Management Division, Montana Department of Agriculture.

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PART 1

GENERAL PLANT DISEASES

CHAPTER I

THE NATURE AND CAUSES OF DISEASE IN PLANTS

A. INTRODUCTION

There are an estimated 100,000 parasitic plant diseases. Fortunately, about 80 percent occur rarely or on a limited scale and are considered relatively unimportant. The annual cost of plant diseases in the United States is five billion dollars.

Plant diseases are the result of the right combination of susceptible host plants, a virulent pathogen (disease causing agent), and suitable climatic conditions experienced during the growing season. Variations from the characteristic or normal climatic patterns are often responsible for sudden outbreaks of certain diseases that would not normally occur. Regional climatic conditions are a major factor in determining crops that can be grown profitably and the prevalence of diseases on these crops.

Plant diseases are divided into parasitic or nonparasitic. The non-parasitic or physiological diseases include; 1) nutrient deficiencies or excesses, 2) environmental extremes, 3) air pollution and pesticide injury, 4) drought, 5) genetic abnormalities, and 6) other physiological disorders.

Parasitic diseases are caused by living "organisms" which can multiply and spread from infected to healthy plants. Organisms commonly causing parasitic diseases are fungi, bacteria, viruses, mycoplasmas, and nematodes.

B. FUNGI

Fungi are simple microorganisms lacking chlorophyll and therefore are unable to manufacture their own food. Fungi obtain their food from living plants and animals or from decaying, nonliving, organic matter. There are about 8,000 parasitic fungi causing 80,000 of the known 100,000 plant diseases.

Most fungi are rather inconspicuous and can be seen only with the aid of a microscope. A number of fungi, yeast, mildews, and mushrooms are readily visible and are known to almost everyone.

Fungi may enter a plant through wounds, natural openings, or by penetrating directly through the epidermis (outer plant tissue).

Vegetative growth (mycelia, hyphae) of the fungus usually gives rise to reproductive structures producing fungal spores which act to spread the disease from infected to healthy plants. The life cycle of certain fungi is extremely complex and may involve a number of different spore stages and more than one plant host.

Fungi cause local or general disintegration of plant cells or tissue, stunting of plant organs or entire plants, or abnormal vegetative growth, all of which are detrimental to the plant and may result in its eventual death.

Fungi may affect plant growth by:

1. Removing or blocking the movement of nutrients essential to plant growth.
2. Producing and secreting certain substances such as enzymes or toxins which affect the structural and metabolic activity of plants.

C. BACTERIA

Bacteria are one-celled microorganisms found in all types of air, soil, and water and are common on or in all plants, animals, and man. Individual cells can be seen only with a high powered (900 x) microscope. There are over 170 species of bacteria causing diseases in plants.

Bacteria reproduce by simple cell division at extremely rapid rates. If a single bacterium divided to produce two new cells and all its descendents did likewise every 20 minutes for just 12 hours, 70 billion bacteria would be produced. In 24 hours, 2,000 tons of bacteria would be derived from just a single cell. It's no wonder that flowers, fruits, and vegetables sometimes rot and wilt so quickly. Fortunately, bacterial reproduction is limited by nutrients, temperature, and availability of space.

Bacteria enter plant tissue through wounds or natural openings such as stomata on leaf surfaces. Once inside, pathogenic bacteria multiply rapidly, kill cells or cause them to grow abnormally, break down tissue, and often migrate throughout the plant. Certain bacteria, like several fungi, produce chemical toxins that poison the plant.

Bacteria are spread by man through cultivation, pruning and transporting diseased plant material such as seeds, bulbs, nursery stock, or transplants. Animals, insects, mites, nematodes, splashing rain, flowing water, and wind-blown dust are also common disseminating agents for bacteria and fungus spores.

D. VIRUSES

Viruses are complex macro-molecules composed of ribonucleic acid with a protective protein "overcoat". They resemble the chromosomes present in all living plant and animal cells - both are self-reproducing nucleoproteins. Viruses can only function and reproduce in a living animal or plant cell.

Viruses divert normal growth and development processes in plant cells causing stunting, yellowing, mosaic, ringspot, or streak symptoms. Virus diseases are difficult to identify in the field and are often confused with nutrient deficiencies, insect or mite injury, and certain genetic abnormalities. Positive diagnosis of viral diseases usually requires the inoculation of specific indicator plants or special laboratory techniques.

Some plant viruses are quite infectious and can be spread easily from diseased to healthy plants by mere contact. Others are transmitted by vectors such as insects or nematodes. Most viruses can be spread by grafting or budding, or by vegetative propagation (e.g. cuttings, root division). Thirty or more viruses are disseminated through infected seed or plant pollen. Viruses often "overwinter" in weeds or in the bodies of insects or mites.

E. MYCOPLASMA DISEASES

Mycoplasmas are bacteria-like organisms without cell walls. Most of these cause "yellow" or "witches' broom" type symptoms in plants. Several well-known antibiotic drugs, including tetracycline and chloramphenicol used to treat a type of pneumonia in man, are very effective in controlling aster yellows and other diseases caused by mycoplasmas. Plant infecting mycoplasmas have been found in leafhoppers. This insect is the principle vector of certain yellows-type diseases.

F. NEMATODES

Nematodes are microscopic, unsegmented roundworms - often called nemas or eelworms. They occur in water and soil. Most are harmless, feeding primarily on decomposing organic material and soil organisms.

Nematodes injure plants by sucking out plant juices through hollow, spear-like mouth parts (stylet). Nematode feeding lowers the natural resistance, reduces the vigor and yield of plants, and affords easy entrance for wilt, or rot-producing fungi and bacteria. Nematode-damaged plants are often more susceptible to winter injury, drought, disease, and insect attack.

Some nematodes enter plant tissues to complete their life cycle, while others remain outside with only their feeding parts attached to the roots. All plant-parasitic nematodes reproduce by laying eggs. Larvae hatch from the eggs and initiate disease during their feeding.

Nematodes generally take several years to build up damaging population levels in soils. They are easily spread by any agent that moves infested soil, plant parts, or contaminated objects. Nematodes are most prevalent in warm, southern regions of the United States especially in light, sandy soil. Diagnosis of plant-parasitic nematodes can be done only by trained nematologist working in a well-equipped laboratory.

CHAPTER II

THE PRINCIPLES OF PLANT DISEASE CONTROL

A. INTRODUCTION

Effective plant disease control is based on thorough knowledge of diseases likely to appear in an area, the plants susceptible to attack, plus an early and accurate diagnosis of the problem.

Control measures must start at the early onset of disease - preferably before symptoms appear. Control starts with the purchase of the best seed or planting materials available, continues in the seedbed, and is maintained throughout the season.

Five fundamental principles of plant disease control are recognized. These are: Exclusion, Eradication, Protection, Host Resistance, and Biological. All cultural practices, and the chemicals used to keep plants from becoming diseased fall into one of these five categories. Sometimes there is considerable overlapping among and between these principles. All five may be used alone or concurrently to protect plants.

Outlined below are general explanations of these principles, how each controls disease, plus some examples.

B. EXCLUSION

Exclusion is the prevention of disease-causing organisms from entering and becoming established where susceptible plants are growing - in a seedbed, garden, locality, state, or country - through federal and state embargoes, quarantines, inspections, and disinfection of plants, seeds, and other propagative plant parts. More than 150 countries now have established quarantine regulations.

About 650 USDA plant quarantine inspectors are our first line of defense against alien pests. Each year, at a cost of about $40 million, these technically trained people intercept some 650,000 lots of prohibited plant material through inspection of people, baggage, mail packages, plus ship and airplane stores.

More than 50 percent of the major plant diseases and pests in the United States have been introduced from foreign countries. Since 1912, our plant quarantine system has saved America billions of dollars by reducing sharply the rate at which destructive plant pests have gained entry from other countries and offshore islands. Examples of alien pests include the Gypsy moth, European pine and spruce sawflies, Japanese beetle, chestnut blight, Dutch elm disease, and white pine blister rust. These diseases and pests, plus others, cause losses of several billion dollars each year in the United States.

Other methods of exclusion include certification of plants, cuttings, and seed. This may mean heat or chemical disinfection of small plants, seed, bulbs, corms, and other parts by producers or governmental agencies before shipment (see under Eradication below). Indexing to ensure planting stock free of fungi, bacteria, and viruses is also an important exclusion practice.

Sometimes restricted entry of planting material is allowed. The plants are grown in isolation and are inspected frequently over one to two years before distribution is permitted.

C. ERADICATION

Eradication is the elimination of the disease-causing agent or pathogen after it has become established on or in a plant where the plant is growing or stored. Eradication is established by rotation, removal of diseased plants or infected parts, destruction of wild or other overwintering host plants, seed or plant treatment, surgery, soil treatment, and a variety of sanitary measures.

1. Crop Rotation

Continuous culture of one kind of plant, especially where crowded together, provides an opportunity for the perpetuation and increase of pathogens and build up of disease. This is prevented by rotating annuals or biennials in seed and flower beds and by growing the same or closely related plants in the same soil only once in three to five years. This practice "starves out" most organisms causing leaf, flower, and stem diseases. These organisms normally persist in soil only as long as host plant residues persist, usually only a year or two. Rotation is not effective against soil inhabitants - fungi and bacteria that subsist in soil up to 10 years or more in the absence of host plants. Many root-rot and wilt-producing fungi (e.g., *Aphanomyces*, *Fusarium*, *Phytophthora*, *Pythium*, *Rhizoctonia*, and *Verticillium*) may survive indefinitely in soil, making eradication by rotation impractical.

2. Destruction of Overwintering Hosts

Perennial and biennial weeds are often a source of disease-causing pathogens. Eradication breaks the life cycle of the pathogen and controls disease. Examples include a wide range of virus and mycoplasma diseases of all types of plants. Aphids, leaf-hoppers, and thrips feed on weed hosts, pick up the virus or mycoplasma, fly to landscape plants, feed, and infect them. Chokecherries, wild plums, and other *Prunus* species are the primary source of infection to flowering cherries, plums, and almonds. Viruses and mycoplasmas causing cucumber mosaic, aster yellows, tobacco mosaic, spotted wilt, plus tomato and tobacco ringspots infect hundreds of different weeds, crops, and landscape plants alike. Control of weeds by cultivation, mulches, and herbicides is an important practice.

3. Seed or Plant Treatment

Control of pathogens within seed, bulbs, corms, and other parts, by wet or dry heat or a systemic plant health product, is becoming common by producers and governmental agencies. Hot water dips are used to kill root knot and other nematodes in roots of numerous plants. Such treatment of dormant plants or propagative parts also controls a wide range of organisms causing seed, bulb, corm, stem, rhizome and root rots, wilts, leaf spots, mites, and insects.

Successful eradication by hot water is dependent on killing pathogens and pests at a certain temperature and time which causes little or no injury to the treated plant or part. Hot water treatment is best done by large producers or agencies having properly calibrated equipment.

New systemic fungicides, such as carboxin (Vitavax), benomyl (Benlate, Tersan 1991), thiabendazole (TBZ, Mertect, Tecto) and thriphanates (Topsin, Fungo) are used for eradicating fungi within plant tissues. Streptomycin is useful as an aid to prevent fire blight and some other bacterial infections. With additional research we can expect more systemic chemicals to be used in the future, either alone or in combination with other plant health products (see also under Chemotherapy below).

4. Surgery

Pruning and removal of twigs and branches of woody plants affected with fire blight and other bacterial or fungal cankers is widely practiced. Other examples include removal of wood-decay in tree trunks and limbs, excision of crown gall-diseased tissue, and cutting out bacterial soft rot in iris rhizomes.

5. Soil Treatment

This method is useful for potted plants, seed beds, greenhouses, and certain outdoor plantings. Annual treatment is usually necessary to keep down nematodes, soil-borne fungi and bacteria, insects, mites, and other pests. Preplant soil fumigants that control a wide range of soil-borne organisms and pests include Vorlex, methyl bromide, chloropicrin, Vapam Soil Fumigant, (Mylone, Soil Fumigant M, Mico-Fume 25-D), and formaldehyde. Ethylene dibromide (EDB), DD or Vidden D, Dorlone, Nemagon or Fumazone, and VC-13 are useful where nematodes are a problem. Mixing of Captan, Folpet, thiram, zineb, chlorothalonil (Daconil 2787), maneb difolatan, or Ferbam with PCNB (Terraclor), benomyl, chloroneb, Truban, Terrazole, or Dexon is helpful in controlling a wide range of soil-borne fungi. These fungicides, plus Nemagon and Fumazone, can be used at or after planting time with a high degree of safety.

Steam or dry heat is widely used to pasteurize soil for potted plants, greenhouses, and some outdoor beds. Soil treated with steam or certain fumigants needs to be covered with plastic to retain the steam or chemical in soil for the required time. It is important not to contaminate treated soil because disease losses may be greatly increased over untreated soil.

6. Sanitation

Practices include a clean and deep plowdown, disinfection of tools, machinery, and storage facilities, plus destruction of diseased plant refuse.

a. Clean plowing or burial of plant debris helps reduce the overwintering or oversummering inoculum of pathogens causing foliar and fruit diseases. It works best for low-growing annuals or biennials that can be shredded to facilitate complete burial in the soil.

b. Disinfecting machinery and tools with steam, hot water under pressure, formaldehyde, or methyl bromide (all materials must be carefully covered with a gas-proof plastic cover) is essential to prevent spread of soil-borne pathogens from one greenhouse or flower bed to another.

c. Disinfecting storage areas, crates, baskets, and sacks is needed to prevent carryover from one season to the next of various storage-rot fungi and bacteria in bulbs, corms, rhizomes, tubers, and roots. Sweeping the storage area clean, followed by thorough spraying of all surfaces with copper sulfate (1 pound of copper sulfate in 5 to 10 gallons water) or 38 percent formaldehyde (1 pint of 10 gallons) is very effective. If the storage area is air-tight, chloropicrin or tear gas may be used at the rate of 124 pounds per 1,000 cubic feet of space. Wait at least 24 to 28 hours - or until all chemical odor has gone - between treatment and storage of fresh plant materials.

d. The destruction of plant refuse is valuable for preventing the overwintering of bacteria, thousands of leaf, stem and flower-infecting fungi, as well as insects, mites, nematodes, and other pests.

e. Eradication of alternate hosts can be expensive programs, but are successful in special situations and will also aid in reducing the development of new races of rust fungi. Examples of this practice include programs to eradicate Ribes spp. (such as currants and gooseberries) which are alternate hosts of the white pine blister rust fungi and similar programs to eradicate junipers and red cedars, the alternate host of a rust fungus that will also attack chockcherry, crab apple, hawthorn, mountain ash and other useful tree species. Probably the most well known eradication program in Montana was eradication of the barberry, an alternate host to the stem rust found on small grains. Destruction of the less desirable host plants is usually needed for a distance of several hundred yards or more around the crop to be effective.

D. PROTECTION

The placing of a protective barrier between the susceptible part of the host plant and the disease agent or pathogen is a common method of disease control. Here it is assumed that the pathogen is likely to be or is already present where susceptible host plants are to be grown. Protection usually means application of sprays or dusts to the plant before air, water, or insect-borne fungal spores arrive. The spores germinate in drops of water into which some fungicide has dissolved. The spores are thus killed before entrance into the plant can occur. Protection also includes killing of insects, mites, or other inoculating agents before these pests can feed and infect plants with pathogens carried on or in their bodies.

Previously, we have suggested protective chemicals to control disease caused by fungi, bacteria, mycoplasmas, nematodes, and other pests. To be successful, the right chemical at the right concentration must be applied at the right time and in the right way. Several applications are usually needed to keep expanding foliar and fruit tissue covered with a protective film and because most modern pesticides are designed to "break down" in 7 to 10 days to form nontoxic compounds. Rain also washes some pesticide away.

Some seed treatments, such as Captan or Thiram. are protective against seed and soil-borne organisms.

Creation of an unfavorable environment for the pathogen during growth, storage, and shipment is an effective means of protection. It includes such practices as:

1. Locating seed production in low rainfall areas where moisture is supplied by furrow irrigation. Here it is usually too dry for fungi and bacteria to infect flowers and fruit; the result is healthy, pathogen-free seed.

2. The time and depth of planting often helps prevent certain diseases when seedling or planting occurs when soil moisture and temperatures are favorable for plant growth but not for the pathogen. Examples: Deep planting may result in excessive Phytophthora crown rot to woody plants, pre-emergence, damping off of young seedlings, and decay or shoot blight of flowering bulbs. Early or late plantings often escape migrations of virus - and mycoplasma-carrying insects. As a general rule, it is advisable to plant cool season crops in cool soil and warm season crops in warm soil to minimize soil-borne diseases.

3. Excessive soil moisture in the seedbed or field commonly increases seed decay, damping off, and root rot diseases. Where possible, avoid planting annuals and most perennials in areas where soil drainage is poor or where water stands for several days following rains. Other possibilities for these problem spots are to grow plants that thrive in water or swampy soil or convert these areas into small lakes.

4. Fertilize based on soil or tissue tests. Essential macro- and micro-elements, when kept in balance, increase plant resistance to many fungal and bacterial infections. For example, excessively high applications of nitrogen, when available potassium and calcium are low, greatly increases losses from such diseases as fire blight, stem and storage decays, Botrytis blights, powdery and downy mildews, many leaf spots, and rusts.

   A deficiency of an essential element such as boron, copper, iron, magnesium, manganese, and zinc may be involved directly in the development of noninfectious diseases. Most landscape plants grow best at a soil pH of about 6.0 to 7.0 where most essential elements are readily available to roots. This is not true of certain plants (andromeda, boxweed, camellia, gardenia, leucothoe, mountain laurel, New Jersey tea, rhododendron, sweet gum, and white cedar) that grow best in acid soil.

5. Temperature and moisture in greenhouse air and soil can be regulated to prevent development of leaf, flower, and fruit diseases as well as foliar nematodes. Free water on the foliage, from careless watering or syringing late in the day, is necessary for infection by most bacteria and fungi as well as all nematodes. High relative humidity, unless controlled by heat and increased air circulation, favors development of powdery mildews, Botrytis blights, leaf molds, and other diseases. Wider spacing of plants in flower beds and landscape plantings promotes rapid drying following wet periods and thus checks development of foliage, flower, and fruit diseases.

6. Care in handling plants and propagative parts during harvest and storage pays big dividends. Sorting out bruised, cut, or rotted bulbs, corms, roots, and tubers at harvest prevents storage rots, especially when combined with temperature and humidity control.

7. Chemotherapy, the treatment of disease by chemicals working internally to kill, inactivate, or protect against the pathogen without injury to the host plant, is a promising means to control. Systemic fungicides (or chemo-

therapeutants) are absorbed and transported within plants to control certain diseases for several weeks or months. To be effective, a chemical must be taken up by the seed, leaves, roots, or stems and be transported in an active state to where infection occurs. Some fungicides with chemotherapeutic activity include benomyl, chloroneb, TBZ, carboxin, oxycarboxin, and oxyquinoline compounds (Bioquin 700, Chinosol, Fulex A-D-O, Sunnox, Wilson's Anti-Damp). Benomyl, and to a lesser extent TBZ, show promise in controlling Dutch elm disease, Fusarium and Verticillium wilts, powdery mildews, blossom blights, black spot of roses, plus killing the overwintering stage of certain fungi (e.g., crab apple scab). Oxyquinoline compounds, chloroneb, and Truban are applied to soil and control a range of flower diseases; oxyquinoline materials are also useful in orchid disease control. Carboxin (vitavax) is effective against seed- and soil-borne smuts and several damping off fungi, while oxycarboxin (Plantavax) is applied to seed, soil, or foliage to control rusts.

E. HOST RESISTANCE

Host resistance is control by growing resistant or tolerant plant varieties.

Development of resistant varieties is usually the most effective and economical means of controlling plant diseases. Plant species, evolving over countless centuries, are normally highly resistant to prevalent pathogens where they are native. When man introduces hosts or pathogens into new areas, widespread devastation is not uncommon. Good examples are Dutch elm disease and chestnut blight, both native to the Orient.

The primary objective in breeding is to combine disease resistance with other desirable agronomic or horticultural qualities. A few examples: Flowering crab apples with multiple resistance to scab, rusts, powdery mildew, and fire blight; new bluegrass cultivars resistant to *Helminthosporium* leaf spots and melting-out, powdery mildew, rusts, and leaf smuts. African marigolds, carnations, china asters, chrysanthemums, gladioli, mimosas, stock, sweet peas, and wallflowers resistant to Fusarium wilt are widely grown. Crepe myrtles resistant to powdery mildew are available as are snapdragons and hawthorns to rust, and firethorns to scab. One of the most successful breeding programs has been the development of stem rust resistant wheat varieties.

For several reasons, woody ornamentals and shade trees have received much less attention by plant breeders than agronomic, vegetable, and fruit crops. Giant strides can occur, however, if more research money and manpower is made available.

F. BIOLOGICAL CONTROL

Biological control can be defined as the regulation of pest organisms by their natural enemies. Biological control has two basic aspects. Classical biological control is the control of pests by introduced natural enemies. Natural biological control is control of a species having the potential of becoming a serious pest but failing to do so because they are restrained by natural enemies. The preservation and augmentation of naturally-occurring biological control agents is a key consideration in pest management.

Initial work done world-wide indicates a great potential exist in the area of biological control of plant pathogens and nematodes. Little is known about their roles as parasites, predators, pathogens or microbial antagonists. Similarly, little is known about the effects chemical programs have on naturally occurring biological control of these organisms. As research continues in this area, we can expect many new and important controls to replace some standard methods now used.

One area of biological control is competition of soil microbe antagonists with some soil-borne plant pathogens. Soil is enriched with organic matter and non-pathogenic soil organisms that can successfully compete and replace several common soil-borne plant pathogens. An example of this is the use of the fungus Trichoderma that competes with Sclerotinia, Pythium, Fusarium, Rhizoctonia, and Thielaviopsis. This is often referred to as "suppressive soil".

One spectacular success in the biological control of plant pathogens is the control of crown gall (Agrobacterium tumefaciens) by a highly competitive, non-pathogenic strain of Agrobacterium radiobacter. This bacterium produces a protein (Bacteriocin) which acts as an inhibitor of related bacterial strains, thus preventing crown gall infection of young nursery stock through ecological exclusion. Research for bacteriocins of other important plant pathogens is continuing. Bacteriocins have potential as an excellent biological control agent because they tend to have a narrow host range and testing is fairly simple. They are common proteins and should, therefore, be environmentally safe.

Some microorganisms are also found that produce antibiotics against other organisms. This phenomenon is not clearly understood but it has potential as another biological control tool. In general, antibiotics are not as host specific as bacteriocins.

G. INTEGRATED CONTROL OF PLANT DISEASES

The concept of integrated control of plant diseases has been developed and applied by plant pathologists for many years. Only recently has it become necessary to define this concept more precisely.

Integrated control of plant diseases involves the same practices utilized in integrated insect pest management. Plant disease management includes selection of adapted, resistant varieties; environmental manipulation; biological control, and the use of fungicides based on economic thresholds of the disease level.

Effective use of these management principles requires detailed knowledge of the host, the pathogen, and the environmental effect on their interaction. There are nearly 100,000 known parasitic plant diseases. The facts required to make control decisions are not always at hand. Few persons are trained to make accurate and correct diagnoses essential to the process of recommending management methods.

Integrated pest management is probably used more than many people realize. Many growers use different types of control methods without realizing that they are using an integrated pest management program. Development of integrated plant disease management is hampered by the formation of new races or biotypes of plant pathogens; weather conditions that are conducive to epidemics; absence of records on disease occurrence, spread, severity and estimated crop losses; lack of adequate biological controls; lack of personnel trained in field diagnosis;

and the absence of data on the economic thresholds of plant diseases.

There is tremendous potential for improving integrated plant disease management. There is need for more plant disease research followed by educational efforts, regulatory work by state and federal agencies, and input from the private farmer or grower regarding his requirements to produce and protect quality food and fiber.

Sound culture and chemical practices based on the principles outlined above will enable growers, farmers, and homeowners to maintain and improve this record. A healthy and productive environment for Montana is our primary goal.

CHAPTER III

PROCEDURES IN FIELD DIAGNOSIS ON AN UNKNOWN PLANT DISEASE

A. INTRODUCTION

Disease diagnosis is based upon symptoms and signs, as in medicine, especially where a laboratory is not available. To help us do a better job in the Plant Disease Clinic, you should:

1. Eliminate the possibility that the abnormal condition observed may be the result of injury caused by rodents, insects, or other animals. Check the water table, particularly if it is near the surface. High water tables may cause a "physiological drowning out", or salt injury. A soil auger is also essential for such determinations. The plant, on the other hand, may be declining from lack of water. Here again, an auger may be useful. The quality of the water must also be considered. Does it contain toxic quantities of salts or factory wastes? Mineral deficiencies cause many plant diseases, usually when they are lacking or tied up in forms unavailable to the plant.

2. Know what diseases have been described as occurring in the crop being examined.

3. Know which of these diseases commonly occur in your area.

4. Know the symptoms that will be useful in distinguishing between the different diseases that you are likely to encounter.

5. Know what a normal, healthy plant looks like. Be acquainted with the major varieties and their growth habits. In other words, you must know the crop. "You can't substitute for experience" according to the wise old owl.

B. FIELD DIAGNOSTIC FACTORS

The following are some questions and points that must be considered when investigating a disease in the field:

1. The Distribution of the Disease

Is it over the entire field or does it occur in spots?

If it occurs in spots, what is different about these spots? Are they in low or high ground or could there be some other difference such as a sand or gravel layer near the surface, or soil dumping area, soil compaction, poor drainage, etc.?

2. The Crop History and the Method of Handling

Is this the first time for this crop or has the same crop been planted in this location previously?

What about the fertilization practices, spray program, irrigation program, or unusual weather conditions during the past month or season?

Has anything unusual been done in the field during the past few years?

Have herbicides or soil sterilants (fumigants) been used to eradicate noxious weeds?

Have insecticides or fungicides, other than those normally recommended, been applied?

Has there been smog or other toxic gases in the area?

What was the source of planting stock or seed?

Was this seed certified, registered, or inspected?

3. Make a Thorough Examination of a Number of Infected Plants

Move about in the field and examine infected plants throughout the entire area. Observe the symptoms.

Are the symptoms systemic as in the case of root rots, wilts, and certain physiogenic disorders associated with nutrition?

Are the symptoms localized in the form of leaf spots or killing, either on the leaf margins or along the veins, or scattered at random over the leaf surface?

How does the diseased plant differ from the healthy plant in color, size, and degree of maturity?

Are there indications pointing to the cause of the trouble, such as fungal fruiting bodies, mycelium, sclerotia, molds, mildew, and rust or perhaps indications of insect injury such as chewed leaves, tunnels in stems or roots, droppings (frass), holes, or mite eggs?

Are the terminal shoots, blossoms, or fruits wilted, discolored, or rotted?

4. Examine Foliage Symptoms in Great Detail

Study the injury, observing its color, size, shape (angular or circular) and note the margins, observing whether they are definite or indefinite.

Is there a water-soaked appearance, a velvety growth or discrete black spots on the injured tissue? Note whether the disease spot of the leaf is cut out, resulting in a shot-hole condition and whether there are accompanying symptoms such as yellowing of the diseased leaves.

Are there malformations or overgrowths on the leaves, stems, or roots?

Has defoliation occurred, partially or fully?

What is the color of the damaged leaves at the time defoliation occurred?

5. There are Several Important Points to Examine in Cankers on Stems

Check the extent of the area covered by the canker, either large or small, and whether the dead area extends deep into the stem or occurs only near the surface. Note whether the surface is smooth, rough, or scaly. On some cankers, fruiting bodies of the fungus may be seen resembling blisters or nailheads or small pimple-like dots.

6. Fruit Rots

Does the rot occur on immature fruit or only on ripening fruit near harvest?

What is the size and location of spot (lesion) on the fruit?

Is the tissue sunken and is there evidence of fungal fruiting bodies?

Is the rot dry, watery, soft, pithy, or spongy?

7. Root Rots

Declines in plants often result from infection by certain soil fungi. These are seldom discovered until the above ground part of the plant begins to show disease symptoms. Such foliage may be wilted and light colored, either on one side or over the entire plant. Check for fungus growth beneath the bark or for discolored vascular system.

8. Consider All the Symptoms and Information Available

Have similar symptoms been seen before either in this crop or related crops?

Can you pick out one or more key symptoms such as mottling, yellowing, or necrosis that might suggest a recognized virus or deficiency?

Is there a pronounced wilting or a dying of the crown or terminal leaves?

What is the condition of the root system?

C. LABORATORY AIDS TO CORRECT DIAGNOSIS

After thorough examination of specimens in the field, and a consideration of the distribution, previous occurrence, and cropping history, you probably will have suspected that the disease in question is one of several that, from previous reading, you know occurs on the crop under consideration. You know that the disease may be caused by a virus, mycoplasma, fungus, bacterium, nematode, or an upset in the physiology (culture) of the host. How do you determine which of these, or possibly a combination of these causes is involved?

If you can't track down the answer, submit a specimen(s) to the Plant Disease Clinic at Montana State University. Please use a Specimen Identification Form that you can get from your county agent. Specimens will be checked with a microscope for the following:

1. Is there evidence of mycelium or spores on the surface of the lesions?
2. Is it in the phloem (suggestive of virus diseases) or xylem (suggestive of fungus diseases)?
3. If the vascular tissue is discolored, is there evidence of mycelium?

4. If we suspect an organism that can be cultured, portions of tissue will be plated out on appropriate agar media and the organism isolated in pure culture.

5. To prove absolutely beyond a doubt the relationship of the organism with the disease, inoculation must be made into healthy plants, again reproducing the symptoms initially observed. The final step is to recover the same organism from the inoculated plants that were first obtained from the diseased plants. This sequence is referred to as Koch's postulates of pathogenicity.

If a virus is suspected, tests may be made in the greenhouse using various host plants that will aid in identification of the virus. It will be necessary here to demonstrate transmissibility by mechanical inoculation, budding, grafting, or dodder. For positive identification, it may be even necessary to make tests of the physical properties of the virus and to determine the vector, probably an insect, and demonstrate virus transmission by the vector.

CHAPTER IV

MODERN FUNGICIDES AND THEIR USES

A. INTRODUCTION

A fungicide is a chemical that kills or inhibits fungi. Fungicides are widely used to protect plant seeds, foliage, fruit, and roots against disease-causing fungi, as well as to preserve wood against decay. Wood preservatives are not covered in this report. No single fungicide is suitable for all purposes or is effective against all fungi.

Recent research is beginning to show that natural deterrents to plant diseases, similar to the predators and parasites that reduce the populations of insects and mites do exist. Additionally, we do have varieties of plants that are resistant to one or more diseases, however, these may lose their resistance as new strains of various pathogens develop. Thus, controlling plant diseases is a perennial problem for anyone involved in growing plants. An unhindered plant disease may be most devastating. Fortunately, we have plant health chemicals that can be employed to alleviate many plant disease problems. The estimated, annual usage of fungicides throughout the world is several hundred million pounds. The annual cost of these chemicals, the expense involved in their application, the the labor associated with control measures for plant diseases runs into hundreds of millions of dollars. Even with the use of disease-resistant varieties, fungicides, and other disease-control practices, the estimated losses from plant diseases in the United States total almost $4.25 billion annually.

1. Protective fungicides are applied to seed, foliage, flowers, fruits, or soil as sprays, dusts, or granules to keep disease-causing fungi from entering plants. These materials provide protection, but do not (a) kill fungi established within a growing plant or seed with the following exceptions: powdery mildew and sooty mold fungi that are superficial and largely on the surface of plants can be killed by surface dusts or sprays, after infection has occurred, without injuring the host plant; (b) protect against disease-causing organisms entering through the roots, e.g. root rots, wilts, and clubroot; (c) control bacterial diseases, since most fungicides are poor bactericides; (d) protect against viruses or mycoplasmas which are frequently injected into plants by insects; or (e) control nematodes.

   Most fungicides in use today possess protective qualities. Those that are only protective include zineb, thiram, ferbam, ziram, sulfur, glyodin, captan, dithane, inorganic copper materials and many others too numerous to mention. These chemicals must be applied before an infection starts. They require frequent applications at seven to fourteen day intervals, depending on the weather conditions. During rainy weather, sprays need to be applied at shorter intervals.

   Practically all dust and granule formulations function as protective fungicides and should be used accordingly. Dusts should be applied when the air is calm and foliage is lightly covered with moisture. Early morning or evening are ideal times.

2. Protective-contact fungicides are used the same as protective fungicides, however, another dimension of effectiveness is that of destroying established infections. A commonly used term is "kickback" which means that an infection may be stopped after becoming established. For example, dodine will still provide control if applied 72 hours after apple scab infection has occurred. Thus, it has a 72 hour kickback for apple scab. In other words, dodine can prevent infection, and it also has good contact toxicity to fungus growth. "Contact toxicity" means that the fungicide may either kill or merely inhibit further growth. The list of protective-contact fungicides includes a large number of the most popular ones. Examples would include benomyl, difolatan, folpet, dodine, karathane, lime-sulfur, thiabendazole or TBA, maneb and zinc iron.

3. Systemic fungicides, or chemotherapeutants, are chemicals that are absorbed and distributed within the plant, destroying established infections and hence controlling certain diseases for several weeks or months. Very few chemicals now available work in this way. Examples would include benomyl, thiabendazole (Mertect, Tecto, Tobaz), chloroneb (Demosan, Terson SP), carboxin (Vitavax), oxycarboxin (Plantvax), oxyquinolines, and terrazole (Koban or Truban). To be effective, a systemic fungicide must be taken up by the seed, foliage, roots, or stem(s) of the plant and be transported in an active state to where disease infection occurs.

   Streptomycin, a bactericide, is typically systemic when applied to foliage. This means that streptomycin can be absorbed by leaf tissue to inhibit bacterial infection, but does not move systemically from leaf to leaf.

B. MODERN FUNGICIDES

Since 1950, many new fungicides have been introduced into American agriculture. These chemicals have largely replaced such old standbys as Bordeaux mixture, fixed or neutral coppers, lime-sulfur, and wettable or paste sulfurs. The older materials are messy to handle and are corrosive to spray equipment. They also cause injury to plants and often reduce the quality and quantity or the crops they were designed to protect, however, these old standbys still have a place since they are safe, cheap and possess longer residual lives. Thus they are often used in preventing certain tree diseases. Captan, zineb, maneb, zinc iron, ferbam, dodine, folpet, thiram, chlorothalonil, and benomyl are now the most commonly used products. All are considered effective and safe when used according to label directions.

Fungicides are marketed under a bewildering assortment of trade names. To relieve confusion, a set of common or "coined" names has been officially adopted and is now widely used on package labels in place of, or with, the more complicated chemical names (called active ingredients).

C. SEED TREATMENTS FOR CEREAL GRAINS

Cereal grain seed treatment is considered cheap crop insurance for protection against smut. However, results of numerous field trials around Montana indicated that seed treatment rarely provides an increased stand or yield of wheat or barley.

Montana State University plant pathologists recommend that growers routinely plant barley and wheat seed treated with an appropriate fungicide. Seed treatment materials are effective against smuts even at low dosages. Care must be used to avoid contaminating non-seed grain with these chemicals.

If a grower wants to apply his own seed treatment in the drill-box, wettable powders such as maneb, thiram, polyram, and captan are registered for use as dusts. They are more expensive and in some cases not as effective in controlling smuts. Maneb, thiram, and others are effective against seed rot and seedling blight organisms that might cause problems if poor quality seed is planted during cold, wet weather.

If a grower has a problem with loose smut, carboxin (Vitavax or Evershield) is the recommended control. These products are effective against all cereal smuts with the exception of dwarf bunt. It may see widespread use if its price is competitive. Dwarf bunt on winter wheat can be controlled by growing the tolerant varieties Crest or Luke or control can be aided by use of a new fungicide - benzimidazole (Mertect LSP).

D. GENERAL PRECAUTIONS

1. Read and follow the manufacturer's directions and precautions on the label when handling or using seed. These are printed to protect YOU. Underdosage will result in poor disease control. Overdosage may cause some injury to the seed.

2. The seed must be of good quality and should be cleaned before treating.

3. All seed treatment materials are harmful if swallowed and may irritate the skin and mucous membranes. Mark treated seed carefully. Do not use treated seed for feed, food, or oil purposes, even after it has been stored for months or years. Make sure bins, wagons, or other containers used for treated seed are thoroughly cleaned before using for other purposes. ALL TREATED SMALL GRAIN SEED MUST BE PROMINENTLY COLORED TO AVOID MIXTURE WITH FOOD OR FEED (FDA, November 4, 1964). Treated seed left over after planting may be held and planted the following year if it is not overtreated and if it is properly stored in a dry, well-ventilated location (not in a closed, airtight container) and away from feed and foodstuffs. The moisture content of the seed should be kept below 14 percent. It is good practice to have a germination test made on all holdover seed.

4. Avoid inhaling dusts, fumes, vapors, or spray mist when treating. An exhaust system connected to the treater and bagger is highly desirable for safety and comfort. Always treat the seed in a well-ventilated container tightly closed, except when removing contents.

5. When applying dusts, use an approved respirator or dust mask over your nose and mouth. Change the mask filters frequently. Wear an apron, and work with rolled-down sleeves and trouser legs. Wear gloves to cover the hands and wrists. Avoid getting any of the material on your skin. This may cause irritation. In case of contact, wash the skin thoroughly.

6. Store unused chemicals in well-labeled, closed containers in a locked cabinet or room out of the reach of children, irresponsible people or pets.

IF YOU ARE NOT ABLE OR WILLING TO FOLLOW ALL OF THESE PRECAUTIONS, HAVE YOUR SEED TREATED BY A COMMERCIAL OPERATOR.

PART 2

IMPORTANT MONTANA PLANT DISEASES

CHAPTER V

DISEASES OF CEREAL GRAINS

A. INTRODUCTION

Wheat, barley, and oats are some of Montana's most important agricultural commodities. There are over 7 million acres harvested in the state each year. Serious yield reductions can occur from plant pathogens each year without proper control measures.

B. RUST DISEASES

Rust fungi are obligate parasites that can cause the following three major diseases in Montana: stem rust (Puccinia graminis tritici), leaf rust (P. recondita), and stripe rust (P. striiformis).

Rusts have complicated life cycles involving several different sexual and asexual spores on alternate hosts. Generally, they are wind-blown onto grains in the spring from their overwintering areas. A rust epidemic can occur if susceptible host varieties are grown in a favorable environment. Temperatures of 50 to 70°F. (except stripe rust, 30 to 60°F.), combined with moisture for at least four hours, are optimum conditions for infection to occur. The severity of the infection corresponds to the length of the moist period. Younger plants seem to be more susceptible to infection than older, more mature plants.

The best control for rust disease is to plant resistant varieties. Most rusts consist of specific physiological races that will only attack certain varieties of the host plant. Pathogen races can change over a period of time so research for resistant varieties is a continuous process. There are several effective chemical controls for small grain rusts.

1. Stem rust is a serious disease of wheat, barley, oats, and rye. It is found every year in Montana on one or more small grains and grasses. The prevalence and severity depends mainly on the weather, the amount of inoculum (rust spores) blown into Montana in the spring by southerly winds, and the reaction of grain varieties to the rust races present. Primarily, stem rust inoculum must be blown up to Montana from the south where the rust can get an early start, since the spores cannot overwinter in Montana.

   Stem rust fungi cause a reduction in yield due to water and nutrient loss, causing shriveling and light grain weight, lower test weight, reduced quality, and lodging.

   Stem rust fungi form reddish brown pustules on leaves, stems, sheathes, chaff, and beards of infected grain. Pustules rupture the epidermis leaving long, narrow, ragged edges.

2. *Stripe rust* is common on wheat, barley, rye, and many grasses. It requires a cool, humid climate and does well in western Montana intermountain valleys. The rust develops yellow pustules on leaves, sheathes and heads giving a yellow striping appearance. Reduction of yield is due to a decrease of size and number of kernels in the head. Stripe rust has the same general life cycle as stem rust, except that the spores and mycelium overwinter in Montana on plant debris. There is no known alternate host.

3. *Leaf rust* occurs primarily on wheat and to some extent on barley. It needs high humidity to cause serious infection and is found mainly in intermountain regions of the state. Usually only lower leaves are infected, forming orange-yellow, round pustules. Again, the life cycle is similar to stem rust, but in the case of leaf rust, the alternate host is meadow rue. This host seems to play a very minor role in pathogen development. Reduction in yield is severe only if infection occurs early and continues throughout the growing season.

C. SMUT DISEASES

Smut diseases can also cause severe damage and yield reduction in Montana's grain industry. Smut fungi are facultative saprophytes that often persist as soil-borne inoculum. To control these fungi, it is necessary to break the life cycle at its most vulnerable point. The mycelium usually grows along with the growing point of the plant and the spores are formed and become obvious only at the time of heading, with sooty masses of spores replacing the seeds at maturity.

Smut fungi that are important in Montana include:

on wheat - common or stinking bunt (*Tilletia caries* and *T. foetida*)
dwarf bunt (*T. controversa*)
loose smut (*Ustilago tritici*)

on barley - covered smut (*Ustilago hordei*)
brown loose smut (*U. nuda*)

on oats - loose smut (*Ustilago avenae*)
covered smut (*U. kolleri*)

on rye - bunt (*Tilletia* sp.) - rare

on corn - common smut (*Ustilago maydis*)

Smut fungi have different modes of infection. Whether it is a seedling, local, or blossom type, infection will influence the type of treatment and control needed. Both local and seedling infections can be controlled effectively with a protective fungicide. Fungal spores that infect seedlings usually germinate under the same conditions as the seeds and infect the growing point at this time. However, fungal spores that infect the blossom act like pollen grains and infect during flowering, developing along with the seed. This type of infection can only be treated with a systemic fungicide or hot water treatments that can get inside the seed. Other control measures include use of good quality seed, clean seed with a high level of germination, use of locally adapted varieties, proper fertility, and other good cultural practices.

1. Common or stinking bunt causes reduction in wheat yields and gives off a foul, fishy odor that makes the wheat unfit for milling. Infected grain can be fed to livestock without injury, however.

   Common bunt infects wheat seedlings as they germinate. The spores are primarily externally seed-borne, as they don't last long in the soil. During threshing, smutted heads are crushed and spores are spread onto healthy heads. Temperatures of 50 to 60°F. and moisture cause both spore and seed germination. The smut fungi enter the seedlings and grow in the developing point of the plant, eventually turning the kernels into smut balls. Infected heads may look plumper than healthy heads, but it is hard to determine infection prior to heading. Infected plants are often weaker than healthy and more susceptible to other injury.

   Control of common bunt includes use of certified seed and seed treatment. There are several fungicides registered for use in the state that will control common smut of wheat as well as some other seed and soil-borne diseases.

2. Dwarf bunt is found only on winter wheat. Under favorable environmental conditions, it can cause severe problems in Montana. It involves a long, slow infection process needing heavy snow cover, freezing temperatures, and diminished daylight. Yield loss and prevalence of infection can be directly correlated to these weather conditions. Infected plants tend to be ¼ to ½ as tall as healthy plants. Dry, spined spores are formed in the heads. These smut balls shatter, infecting healthy seed and soil. Smut spores germinate along with the seed, infecting the growing point of the plant and growing systemically with the plant. Until recently, the only control recommended for dwarf bunt was use of resistant varieties of winter wheat. Now there is a fungicide registered in the state that aids in control of dwarf bunt when combined with late seeding. Late seeding is also recommended for control of wheat streak mosaic virus, Cephalosporium stripe and Hessian fly.

3. Of the barley smuts, brown loose smut is the most important in Montana because it is the most difficult to control. Covered smut infects only the outer layer and is easily controlled by protective fungicides. Grain infected with covered smut is covered with a membrane and the remnants of the glume. The membrane is easily broken at maturity and the spores are disseminated by the wind. Loose smuts are only covered by a very thin membrane that immediately ruptures, leaving loose spore masses.

   Brown loose smut infects the blossom of the barley and the mycelium is carried in the embryo of the barley seed. Diseased and healthy seeds look identical and surface seed treatment will not destroy the infection. To control this disease, it is important for the grower to buy good, clean seed. Use of certified seed and certain systemic seed treatments have helped control losses to this disease.

4. The other smuts listed aren't usually a serious problem in Montana. Common corn smut may become a problem with increased acreages in the state. The disease appears to be more prevalent in dry areas.

D. FOOT AND ROOT ROTS

Foot and root rots can also cause serious disease problems in Montana. Foot rots involve discoloration of the lower portion of the stem and root rots discolor the roots. Some specific diseases important on Montana grains include dryland foot and root rot (Helminthosporium sativum), take-all root rot (Gaeumannomyces graminis), strawbreaker foot rot (Pseudocercosporella herpotrichoides), and Cephalosporium stripe (C. gramineum). Often these diseases are found in specific, well-defined patches in a field. The best control of these organisms involves residue management, crop rotation, late planting dates, selecting adapted varieties and utilizing a balanced fertility program.

1. Cephalosporium stripe is a disease found on winter wheat. In the spring, the disease can be recognized by yellowed lower leaves. Often there is a definite yellow stripe on the lower leaves and the vascular bundles turn brown. This brown line is a diagnostic characteristic since many other diseases can cause yellow striping. At heading, the symptoms are more evident. Plants exhibit stunted growth, flared awns, and white heads. The fungus overwinters in infected straw and chaff. It is rarely seed-borne, but can be carried with chaff on poorly cleaned seed. Infection is aided by root break during alternate freezing-thawing in the spring. A good way to avoid this is to plant as late as possible in the fall. The fewer roots that are developed, the fewer potential infection sites. The best control measures include rotation with spring-sown or oilseed crops. Planting the less susceptible varieties is another method that gives some control but no exceptional resistant varieties are currently available.

2. Dryland foot and root rot can be a problem on wheat, rye, barley, and certain grasses. If seeds are infected, they may fail to germinate or produce weak, spindly, or stunted plants. Lower leaves turn yellow prematurely and diseased stems turn brown. Badly diseased plants are somewhat dwarfed and die soon after heading out. Heads are often white with poorly-filled, shriveled kernels. The fungus may live for long periods in crop residue, in the soil, or in infected seed. Weather and moisture conditions often determine the destructiveness of this disease because they influence the growth of the fungus as well as the host. More infection occurs when soil temperatures are high (above 60°F.). Weak plants are more susceptible to infection.

   The best control measures include use of good, clean seed, fungicidal seed treatment, late sowing, shallow planting, and approved cultural methods (i.e. summer fallowing, rate of seeding, fertilization, weed control, etc.) No varieties are known that are highly resistant.

3. Take-all fungus can attack most small grains except oats, which are very resistant. The causal agent can survive as mycelium or spores in plant debris. It usually attacks young seedling roots in the early spring. Infected seedlings have a yellow or bronzed appearance and have brown or black lesions on the roots. At maturity, some areas of the field may have a roughly circular area with dwarfed, faded plants that are infected. Heads are often sterile or have shriveled kernels (white heads). The fungus also forms a black mat of fungal tissue at the base of the plant under the leaf sheath.

The fungus cuts off the plant's supply of moisture and minerals to the developing grain. Often the roots are stubbed off at the base of the crown and plants can be easily pulled from the soil.

Control can reduce losses but not completely eliminate the disease. Crop rotation with legumes, oats, spring grains, and oilseed crops that usually escape the disease can help cut down losses. A balanced fertility program has been reported to reduce the disease severity.

4. Strawbreaker foot rot can be a serious problem in localized areas of Montana. It attacks only winter cereals. Symptoms start with pinpoint, water-soaked areas on the outer leaf sheathes. Later, well-developed eye-spot lesions that are nearly white and bordered by brown areas appear. At maturity, diseased plants have an excessive number of dead tillers. Near harvest, diseased culms often buckle and fall, making harvesting difficult. The fungus overwinters on infected stubble and invades susceptible plants in early spring. Entry occurs through direct cell penetration or through stomatal openings.

   Serious yield reductions can occur under certain climatic conditions, usually cool, moist springs. Crop rotation is the best available method to prevent serious outbreaks.

E. LEAF BLIGHT DISEASES

There are also a number of leaf blight complexes that are usually a combination of pathogens, including both fungi and bacteria. Some causal agents of leaf blights include *Helminthosporium gramineum* (barley stripe), *H. teres* (net blotch), *Septoria tritici* (leaf blotch), *S. nodorum* (glume blotch), *Pseudomonas syringae* and *Xanthomonas* sp., which cause bacterial leaf blight. Often these organisms can cause serious losses during prolonged periods of cool, wet weather in the early spring. They generally overwinter on plant debris and produce spores in the spring. These spores can spread rapidly under favorable weather conditions.

Important control measures include crop rotation, deep plowing, destruction of volunteer grasses before planting time, use of certified seed, and plant resistance or tolerance when available.

1. *Septoria nodorum*, causing glume blotch, infects chaff or glumes as well as culms, leaf sheathes, and leaves. In the case of glume blotch, infection is favored by warm, moist weather. This disease is more prevalent in eastern Montana.

   The primary symptoms are tan to brown colored lesions at the axil of the leaf blade and leaf sheath. The warm, moist environment in the sheath causes rapid fungal growth and deterioration of the leaf sheath and subsequent death of the leaf blade. Increased infection on a plant causes a greater potential yield reduction. Pycnidia (small, balck dots) are formed wherever lesions have been formed. When infection occurs at nodes or joints, lodging may occur due to weakening of the straw. Severe infection causes stunting.

2. Barley net blotch and barley stripe, both caused by species of *Helminthosporium* fungi, are distributed through temperate, humid regions of the

world, especially where barley is grown in cooler periods of the year. They are generally of minor importance but can cause foliage reduction.

Symptoms of net blotch include brown reticulate blotches near the leaf blade tip. Young infections show a characteristic netted blotch irregularly distributed. Older infections tend to coelesce the blotches, forming a striping appearance on the leaves. With a net blotch infection, this striping never extends into the sheath.

Barley stripe symptoms become obvious at tillering. First there is a yellow striping of the leaves that will extend down into the sheath area. These areas turn brown and the tissue dies. Usually the culms elongate and often spikes fail to emerge or are blighted, twisted, compressed or brown if they do emerge.

The mycelium from these fungi can remain viable for an indefinite period of time and can be carried from season to season on infected seed and in plant debris. Infection of net blotch occurs usually in early spring or in the fall in cool, wet weather. Infection of stripe occurs soon after flowering and the mycelium becomes established in the pericarp or embryo. Cool, moist, and fertile environmental conditions favor infection and development of both fungi. Free moisture, especially irrigation, is required for stripe development.

The most effective control measures for both diseases include seed treatment, good sanitation methods, crop rotation, and use of resistant varieties.

3. Another leaf disease that can be severe on barley is scald (Rhynchosporium secalis). It is very destructive in cool, wet years, resulting in defoliation and reduced yield.

   The fungus causes dark, blue-grey, water-soaked lesions on the leaf blades and sheaths, changing with maturity to a bleach lesion with a dark brown margin. It overwinters on diseased straw and stubble and on volunteer hosts. The disease spreads as wind-borne and rain-washed spore inoculum.

   Control includes using a balanced fertility program.

F. ERGOT

Ergot (Claviceps purpurea), a disease of grains and grasses, is a problem due to the presence of poisonous alkaloid in the sclerotia. The sclerotia are hard, violet-to-black, horn-like bodies that replace kernels in the grain head. They overwinter in the ground or in contaminated seed. In the spring, sclerotia send out "heads" which produce spores. These spores are shot off and carried on wind currents to blossoming grain heads. The spores germinate, infect the kernel, and replace it with a mold growth which secretes a spore laden, sticky honeydew that is distributed to other plants by insects and rain. Plants are susceptible to infection as long as they are in blossom. The fungal mass in the heads grows larger and becomes hard and finally protrudes from the mature head as the sclerotium (ergot). The sclerotium can germinate only after a period of cold and can survive in storage for two years or longer.

The poisonous alkaloid found in ergot causes contraction of small blood vessels and can be fatal to livestock if heavily infected grain or hay is fed. The tolerance for ergot is .3% by weight. Consumption of small amounts of ergot can produce weakening of livestock, while heavier consumption can cause abortions and spasmotic or gangrenous symptoms with loss of hooves, ear tips, shedding of teeth and hair, emaciation, and eventual death.

The best control is use of ergot-free seed. Ergot sclerotia can be partially removed by fanning of seed. Rotation of susceptible crops with legumes or other non-susceptible hosts reduces overwintering inoculum. Control of heading of grasses surrounding cereal fields and avoiding use of super susceptible varieties can reduce ergot infection and inoculum. On natural pastures, ergot must be controlled by cultural or cropping methods that keep grasses from heading.

G. VIRAL DISEASES

Viruses can also be important on small grains. Wheat streak mosaic virus (WSMV) is a problem on wheat in Montana. Barley stripe mosaic virus (BSMV) is found on barley and barley yellow dwarf virus (BYDV) can infect barley, wheat, oats, and other grains and grasses.

1. Wheat streak mosaic virus development depends on the population level of the wheat curl mite (Aceria tulipae), the closeness of virus-infected plants (especially volunteer wheat) to newly emerging wheat plants, and moisture to keep wheat plants growing vigorously, thus sustaining maximum mite production. Generally, yield losses are more severe on early seeded fall crops than on spring-infected plants because the disease and mites both have more time to become established.

   Even on fall-infected wheat, symptoms do not normally appear until warm weather the following spring. Early symptoms appear as spindle-shaped streaks and striping on leaves. Gradually, the plants yellow and become moderately to severely stunted. They tend to spread out more than normal and develop an abnormal number of tillers. As infected plants mature, yellow leaves turn brown and die. Usually the heads are sterile or have shriveled kernels. Symptoms can vary depending on virus strain, variety of wheat, temperature, time of infection, level of plant nutrition, soil temperature, and other factors.

   Field identification is difficult, therefore, identification should be done in a lab using indicator plants or an electron microscope. The virus can only be transmitted by the mite vector, although some studies indicate possible transmission by direct contact between plants by strong winds. Mite feeding causes wheat leaf edges to curl tightly inward toward the midvein. The mite carries the virus internally for several weeks once they are infected. As winter wheat plants mature, the mites migrate to nearby volunteer wheat plants, grasses or corn, infecting some of these new hosts. The mites can be wind-blown up to 1½ miles from volunteer hosts to early planted wheat. Young mites can acquire the virus after 15 or more minutes feeding on infected plants. The life cycle of the mite is 9 days from egg to egg-laying. Each mite lays an average of 12 eggs. Large populations can develop rapidly on wheat plants and if the virus is present, a serious epidemic can occur. Neither the mite nor the virus can live longer than a day or two separated from a living plant. The virus cannot be carried over on dead plant debris.

Control of the disease is aimed at control of the wheat curl mite. This is best done by destroying all volunteer wheat, wheat stubble, and weed grasses two weeks prior to planting and sowing winter wheat as late as practical. There are no recommended resistant varieties of wheat. Chemical control against the mites has not been successful since the mites are curled tightly in the sheaths and the chemical doesn't reach them. There are no chemicals that are effective against any viruses. All control measures are most effective when all farmers in an area cooperate in an areawide sanitation program.

2. Barley stripe mosaic virus is common in the spring barley regions of Montana, North Dakota, Wyoming, and Canada. It can cause losses up to 20% and reduce test weights by nearly 5%. The problem is perpetuated and increased when infected seed is planted. Crop losses are a result of reduced grain production, dwarfing of plants, smaller stem diameters, fewer heads per plant, semi-sterility, and incomplete head emergence. Disease symptoms vary with virulence of the strain of virus and the mode and time of infection. If the infection is seed-borne, symptoms generally appear as chlorotic mottling or spots that are grayish white, yellowish, white, or yellow or as continuous green stripes. In early infections, the plants can be stunted or dwarfed with poorly developed heads. If the infection is from plant to plant in the field, the same symptoms appear only on growth from the time of infection (i.e. if inoculation occurs in the first leaf stage, spotting and striping appears on the second and third levels).

   BSMV is transmitted primarily by seed-borne virus particles that can remain viable in the barley embryo for many years. Infected pollen can transmit the virus during heading and fertilization. When the seed germinates, the resulting seedling is infected. The virus is also spread to adjacent healthy plants when they are wounded and rub against each other. Symptoms appear within 3 to 14 days after inoculation.

   The most effective control is through use of certified, virus-free seed. Yield losses are proportional to the level of infection in the seed lot, so growers should have their barley seed indexed at the Montana Seed Lab in Bozeman. Barley fields should also be rotated with other crops to control potential sources of viral infection. Seeding equipment should be cleaned before planting to avoid mixing of infected and virus-free seed. There are some resistant varieties of barley, including Betzes, Centennial, Erbet, Hector, and Vanguard.

3. Barley yellow dwarf virus is most serious on barley, but it also infects wheat, oats, and many other grasses. It is most serious when environmental conditions favor the build up of aphid populations that are responsible for the transmission of the disease. Diagnosis of BYDV is difficult because the symptoms can be confused with others that are caused by various unfavorable environmental conditions. Affected barley plants usually show leaf yellowing starting at the leaf tip. Infection can occur at any growth stage of the barley. Very young plants that are infected may be killed. Older plants become stunted and unthrifty. Stunting usually decreases with the age of the plant. The younger the plant when infected, the greater the yield reduction. Wheat symptoms are similar to barley. Oats usually show a more reddish discoloration which may also be seen on wheat and barley. The flower parts may also show blasting from a few

florets to the entire head. Blasted heads are completely devoid of seed and are white. Intensity of symptoms is, again, directly related to the age of the plants when infected. Later infection is recognized by a characteristic reddening of late developing leaves. This may be confused with nutritional disorders. To distinguish between nutritional and viral symptoms, trained observers look for a transition zone between discolored and healthy tissue. This zone is characterized by a mottled appearance in the case of viral infection.

The virus overwinters in winter grain, grasses, and overwintering aphids. In the spring, aphids pick up the disease and carry it to other hosts. The virus is probably always present in the state but only becomes a problem when conditions favor increased development and migration of the aphids involved in transmission to large acreages of spring grains. Important aphid vectors include the corn leaf aphid, English grain aphid, Apple grain aphid, grass aphid, and the breenbug, with the first two being the most important in Montana. The disease is not transmitted through seed or mechanically, nor does it survive in the soil.

CHAPTER VI

DISEASES OF POTATOES

A. INTRODUCTION

About 8,000 acres of land in Montana are utilized for potato production with an average yield of around 240 bushels per acre and an average value of nearly $1,000 per acre. Yield variation from year to year can be attributed to disease and pest loss, unfavorable environmental conditions, and poor cultural practices. Destructive potato diseases found in Montana are caused by parasitic fungi, bacteria, viruses, and mycoplasmas. Non-parasitic agents, such as genetic abnormalities, nutrient deficiencies, and physiological disorders may also contribute to reduced potato yield and quality.

B. FUNGAL DISEASES

1. Black scurf of potatoes is an occasional, yet injurious disease in Montana. It is caused by the fungus *Rhizoctonia solani* which is widely distributed in soil and many strains may attack many different crops.

   Symptoms may vary with climate, soil, host development at the time of infection, and virulence of the fungal strain. In the spring, the fungus attacks roots, stolons, and sprouts, causing the formation of dark lesions or cankers that girdle the sprout and eventually cause death. If plants are attacked after they emerge, the leaves become thick and sparse, roll upward, and turn slightly reddish. The stalks may thicken and form aerial tubers. If stolons are attacked, the food supply for tuber production may be cut off, causing formation of abnormally small tubers. Diseased tubers can be recognized by the appearance of irregularly shaped, dark brown to black patches of fungal threads (sclerotia) on the tuber surface.

   The fungus can live indefinitely in the soil or on plant debris. The sclerotia are the dormant or resting stage of the fungus which carry the disease over the winter and can be carried long distances on diseased plant debris and infected tubers. Under favorable conditions, the sclerotia germinate and invade plants at or below the soil line. Spores are produced on stems just above the soil line.

   Perfect control is difficult since the fungus is so widespread, but a seed treatment combined with rotation with other crops will help reduce field inoculum. Also, proper cultural practices which promote rapid growth of plants aids in escaping the disease. Harvesting as soon as the tubers are mature will also help reduce the number of sclerotia in the soil.

2. Potato late blight (caused by the fungus *Phytophthora infestans*) can be found in small amounts in Montana. It is usually only a serious problem in areas where cool and rainy periods during late summers and fall occur.

   The leaves of the infected plant form blackish-brown, water-soaked spots that eventually enlarge into lesions surrounded by a pale green, water-soaked zone. In very wet weather, a whitish fungal growth that produces spores can be found on the under surface of the leaf. This causes the disease to spread rapidly in cool, wet weather. If the infection is severe, the entire leaf becomes blighted, the fungus moves into the stem, and the entire plant eventually dies. When a large number of plants are infected, the entire field can give off a foul odor. Infected tubers develop reddish-brown spots and a dry, hard rot. Under moist conditions, they can undergo extensive rotting.

The fungal organism overwinters on diseased tubers either in storage or in the soil. It grows vigorously in the spring in cull piles or on volunteer potato plants and about July, the spores are blown to the foliage of the new crop. The spores will germinate when temperatures are above 60°F. and free water is available. Swimming spores are produced, which then penetrate the plant. A five-day cycle is required to produce new spores which spread to healthy plants by wind and splashing rain. Tubers are infected by swimming spores that are washed off the leaves into the soil and generally penetrate through the eyes. Tuber infection is more likely in loose, gravelly soil. The fungus is not spread from tuber to tuber under proper storage conditions.

The most important control measure is to avoid importation of seed potato from blight areas. Destruction of cull piles and volunteer plants by burying or spraying helps destory overwintering inoculum. There are also some chemicals recommended for control that should be applied at the first sign of disease.

3. Early blight of potato is caused by the fungus Alternaria solani. It causes occasional damage in Montana, usually later in the season, two to three weeks prior to harvest. Fungal growth and spread is favored by warm, humid weather.

   Early symptoms occur on older, lower leaves as small, circular to oval, brown and black spots. These spots have characteristic close, concentric rings. The spots may unite, killing large areas and causing a rolling that resembles tip burn. When tubers are affected, they form slightly sunken, small spots with somewhat raised margins. These diseased areas can provide avenues for entrance of other pathogens.

   The fungus overwinters on potato debris. In the spring, spores are formed and spread to new growth by wind, rain, and insects. Under favorable conditions of warm, humid weather, the spores germinate and penetrate the potato leaf, forming lesions and more spores, thus spreading the disease throughout the growing season.

   The best control is destruction of old plant refuse. If a serious infection has occurred in an area, it is important to burn dead vines after harvest. Proper fertilization is also important since some potato varieties are more susceptible if they lack certain nutrients. There are some effective foliage fungicides; these should be applied as soon as spots show on the lower leaves.

4. Verticillium albo-atrum, causal agent of Verticillium wilt, is a common soil inhabitant that tends to build up in areas where tomatoes, pepper, eggplant, and mint have been grown.

The symptoms are indistinct and tend to be confused with other diseases. Diagnosis is difficult and positive identification can only be made by isolating the organism in a lab. The lower leaves wilt and turn yellow. The plant may be stunted and rosetted at the top. A single stem may be infected or the whole plant. The vines may wilt, but with low temperatures and high soil moisture, a typical wilt may not develop. The vine may just mature earlier. Usually the vascular ring of tubers, stolons, and stalks are discolored and infected tubers tend to be smaller than healthy tubers.

The fungus overwinters in soil and on plant debris and can also be tuber borne, so the disease can develop from infected seed pieces or contaminated soil. The spores enter the plant through the roots and penetrate most of the vascular tissue. Depending on crop rotation practices and the strain of fungus present, the spores may persist in the soil from two to seven years.

Potatoes should not be planted in an infected field, especially following diseased potatoes, tomatoes, eggplant, or mint. Long crop rotations including legumes will help to minimize carry-over of the fungus from season to season. Also, late planting will lessen the chance of infection. Soil fumigation is effective but expensive. There are some seed treatments available and some sources of plant resistance.

5. *Fusarium* wilt is caused either by *Fuasrium orysporum*, which causes only wilting or by *F. eumartii*, which can cause both wilting and tuber rot. Infection is favored by high moisture while wilting is favored by low soil moisture.

   The fungus invades the vascular tissue extensively. Infection depends on the plant variety and age. *F. oxysporum* causes a yellowing of lower leaves and rapid wilting of either the entire plant or individual stalks. The fungus is confined to the vascular bundles of roots, stolons, tubers, or stems. Internal discoloration tends to be light brown in color. *F. eumartii* generally yellows the younger leaves first between the veins. Eventual necrosis of these areas causes indefinite small brown patches to develop, a condition often called bronzing. With severe attack, the leaves droop and hang down to the stems. Complete wilting follows. Under moist conditions, there is usually only a slight mottling and bronzing at the upper leaves but new tubers show a high percentage of stem end rot and vascular discoloration. This discoloration can extend into the upper part of the stem and foliage. The tuber may develop extensive watery rot. Excessive soil moisture may cause some rolling, purple leaves, a rosette appearance, and aerial tubers.

   Both fungi overwinter in potato debris in the soil or in infected potatoes in storage. During the growing season, the fungus invades roots and spreads through the plant to the tubers. The first symptoms are seen about blossoming time or earlier if infected seed has been planted.

   The most important control measure is to plant healthy seed potatoes. Crop rotation, late planting, sanitation, and some seed treatment also helps to reduce inoculum and infection.

6. Many potatoes are also lost due to storage dry rots. The causal organism is one of several species of Fusarium, all different from those causing field wilt.

Diseased tubers first show a shrinking and darkening on part of the tuber. The diseased portion has a wrinkled, sunken appearance that later may show cavities and tufts of fungal mycelium. The diseased tissue varies from nearly black to light brown depending on the variety. Under favorable conditions, the fungus rots the entire tuber leaving a dry, powdery mass of decomposed cells, starch granules, fungus mycelium, and spores surrounded by a cork layer on the outside. This rot is dry and does not have a bad odor. Often the fungus attacks the center of the tuber first and rots the interior with little or no outer, visible symptoms or signs.

The causal agent is present in most soils. It does not attack growing plants and can only infect tubers through wounds or bruises. The fungal spores can contaminate the tuber superficially in the field at harvest and can be carried into storage on the potatoes. Infection can then occur any time wounding occurs.

The best control is careful handling to prevent wounding and careful grading to eliminate undesirable tubers prior to storage. Storage areas should be dry, well ventilated, and maintained at temperatures of 35 to 40°F. Cleaning and disinfecting of storage houses also helps in control of storage dry rot.

C. BACTERIAL DISEASES

1. Potato ring rot, caused by the bacterium Corynebacterium sepedonicum, is one of the most serious diseases found on potatoes. It is tuber borne, highly infectious, readily spread, and has a tolerance of zero percent in certified seed potatoes. Table stock loss is due to rot in the field or in storage.

Symptoms occur when the plants are nearing maturity. Lower leaflets begin to wilt and show a slight rolling. The area between the veins turns yellow and leaves tend to curl upward. There is a progressive wilting either of individual stalks or the whole plant eventually causing death. Potatoes grown under cool conditions may mask foliar symptoms but still produce infected tubers. The symptoms can be confused with other disorders, especially Fusarium wilt, however, plants with ring rot show no vascular discoloration of the stem or roots as is the case with Fusarium wilt. One hill can have a combination of mildly and severely infected tubers as well as some tubers with no infection at all. Early infections discolor the tuber just below the surface near the stem end. It is a yellow, cream, or light brown color and is due to the presence of the bacterium in conductive tissues.

It has a cheesy or crumbly consistency and no odor. Any odor associated with ring rot is due to secondary rot-producing organisms. The bacteria spread through the tuber causing central breakdown and eventually a hollow tuber. Infected tubers break down rapidly in transit or storage.

The bacteria can't overwinter in Montana in the soil and is usually found overwintering in diseased tubers or on containers and implements. When an infected seed piece is planted, the organism passes into the foliage, causing wilting. Newly-formed tubers are invaded through stolons. The disease is spread mainly by seed-cutting operations, sacks, decayed tubers and refuse, and contaminated sorters and planters.

The most important control measure is to plant certified, disease-free seed pieces. Use of small, whole tubers or disinfecting the cutting knives can slow spread. Also, all storage areas, machinery, and bags should be thoroughly disinfected prior to use. Seed treatment should be used in conjunction with disinfection. There is some resistance found in Teton, Saranac, and Merrimack seed potato varieties.

2. Erwinia carotovora, the causal organism of blackleg, is common in Montana when warm, moist summer and fall conditions favor its growth.

   Infected plants first wilt or show yellowing of their lower leaves. The upper leaves then become yellow or reddish and roll upward prominently. The lower stem of the plant is girdled and the plant then wilts and dies. The stems near the base have black pith and the tubers generally develop soft rot, starting at the stem end. Often this disease is not detected until later in the season.

   The bacteria overwinter in plant debris and on infected tubers. It is spread by contamination of machinery or cutting knives. The infection begins in the seed piece either from carry-over in the seed piece, cutting contamination, or direct contamination from the soil. The infection then extends upward into the stem. The bacteria can also be spread by root maggots and nematodes.

   Control is similar to control of bacterial ring rot. Any hills showing blackleg symptoms should be rogued out. Diseased plants and tubers should be destroyed.

3. Common potato scab occurs on all commerical potato varieties. It is a soil-borne disease caused by the bacterium Streptomyces scabies. This disease doesn't affect the eating quality, but loss is due to lower market value related to unattractiveness to the consumer and deep paring required. Only very severe infestations reduce yield. It only attacks young, rapidly growing tubers and doesn't develop in storage. The bacterium also attacks on turnips, sugar beets, garden beets, and radishes.

   The first symptoms are small reddish-brown raised spots on the tuber. These spots enlarge in severe cases to cover the entire tuber. Scab lesions vary from superficial (russet, common, or corky) to pitted or raised forms.

   This bacterium is normally present on the soil. Its abundance and behavior is affected by soil conditions. Favorable conditions for infection include light sandy to sandy loam soil type, neutral pH (between 5.2 and 8.0), high soil temperature, and low soil moisture. Animals fed scabby, raw potatoes pass the organism into manure and spread it around.

   Control measures include using clean seed, seed disinfectants, crop rotation, fertilization to acidify the soil and some plant resistance. It is also important to avoid planting in badly contaminated soils and to avoid use of fresh manure prior to planting a potato crop.

D. VIRAL DISEASES

Viruses affect primarily the size and number of tubers produced rather than eating and selling qualities. Overuse of one stock of potato can cause deterioration of vigor, once known as "running out" and now known to be caused by a build-up of virus in the stock population. Viruses are spread by transmission of diseased sap to a healthy plant either through direct contact or sap-feeding insects (primarily aphids).

Typical symptoms of virus infection include dwarfing, distortion, leaf roll, black streaking of veins, and mosaic or mottling, which is the most common symptom. Some tubers show elongation, cracking, and internal discoloration.

1. Mosaics can be classified as either simple, mild, or rugose. They are caused by either a single virus or a combination of viruses. Primary characteristics include mottling symptoms and sap transmissibility.

    a. Simple mosaic infections are caused by either potato virus X (PVX) or potato virus M (PVM). Plants show a mottling in shades of light or dark green that can be barely noticeable to very conspicuous. Symptoms are most obvious in cool, dull weather. There is no noticeable effect on the tubers. Both viruses are contact transmissible.

    b. Mild mosaic is caused by a combination of PVX and potato virus A (PVA). Plants have a light green to yellowish mottle and slightly wrinkled leaves that are smaller than normal. There are no obvious effects on the tubers. PVA is aphid transmissible.

    c. Rugose mosaic infections are caused by potato virus Y (PVY) alone or in combination with PVX. Plants that are infected early by direct transmission (aphid or contact) show black streaks in veins, leaf stalks, and stems, causing leaves to shrivel and hang. Eventually the stem will be bare except for a few leaves at the top (the "palm tree" effect). If plants are infected later in the season, these symptoms may not appear. Plants growing from infected tubers have mottled,wrinkled, distorted leaves that are reduced in size. The leaf stalks are brittle and both plants and tubers can be dwarfed. PVY is aphid borne and there are several strains, so severity and symptoms may vary. The mosaic viruses PVX, PVY, and PVA are all perpetuated in tubers of diseased plants.

    The best control for mosaic viruses is use of certified seed and roguing out any diseased plants when the symptoms are obvious. Application of insecticides to control aphids will aid in limiting the spread of mosaic viruses which are transmitted by these insects.

2. Potato leaf roll can be a problem wherever potatoes are grown and aphids are abundant. Primary infection occurs on any plant that becomes infected during the growing season. The upper leaves begin to roll, become pale

green, and stiffer than normal at maturity. Plants that are infected later in the season may not show foliar symptoms but the tubers may be infected. Some tubers may show net necrosis.

Secondary infection involves plants grown from infected seed pieces. Symptoms appear in young plants as new growth develops. The margins of affected leaves roll upward, tissue becomes dry, leathery, and thicker than normal, and leaves are brittle and rattle when shaken. Plants are usually stunted, light green and erect, while tubers tend to be smaller and fewer in number.

There are several strains of leaf roll virus that are transmissible by aphids. Use of certified seed potatoes and control of aphid populations will help control potato leaf roll.

3. Spindle tuber viroid is not a widespread problem, but is can cause a percentage of infection when it does occur. It is most obvious in hot weather. The vines are erect, narrower, more branched, slightly stunted, and darker green in appearance. The leaves are set at a sharp angle to the stem giving the plant a stiff look. Tubers are usually longer than normal and pointed at the stem end with some cracking. They also tend to have more numerous and shallower eyes. It is spread by contact as well as by aphids and other insects. The most effective control is use of certified seed, as it is also tuber borne.

4. Calico is a virus disease of potato that is caused by the same virus as alfalfa mosaic. Aphids can transmit the disease from infected alfalfa and clover to potatoes.

   Symptoms usually appear late in the growing season. The leaves are strongly mottled with large, irregular, yellow to cream-colored patches. Usually only a few leaves on a vine will show these symptoms. There is some dwarfing of the plants but not of the leaves. Tubers are usually misshapen, cracked, and fewer in number. Control is achieved by destruction of volunteer alfalfa or clover in nearby areas and roguing of diseased potato plants.

5. Yellow dwarf is a virus disease that isn't widespread in most commercial potato fields. Foliage is dwarfed, wrinkled, and yellowish with rough upper leaf surfaces. Growing tips die early and stems develop a yellow tinge that is hastened by dry, warm weather. Diseased stalks often have internal brown spots. The virus is spread by the clover leafhopper (*Aceratagallia sanquinolenta*). The leafhopper carries the virulent pathogen over the winter and can transmit the virus to young plants early in the spring. The most effective control methods involve planting certified seed away from clover fields and roguing diseased plants.

E. MYCOPLASMA DISEASES

1. Purple top wilt is a disease caused by a mycoplasma that usually appears after mid-season. All potato varieties are susceptible, but this disease is of little importance in Montana.

   In plants infected with this mycoplasma, young leaves fail to enlarge, leaflets roll upward, and terminal growth is retarded. Auxiliary buds usually produce many side branches and aerial tubers at the plant base. Leaflets may show purple, pink, or yellow pigmentation and the stems have an internal discoloration. Later in the infection, the entire plant withers and dies. Tubers become flabby and produce spindly, hair-like sprouts. The stem ends are usually discolored also.

The mycoplasma is spread from overwintering weeds and clover by a leafhopper. It is not tuber borne. Control methods include weed control, leafhopper suppression, certified seed, and location of fields away from clover crops.

2. Witches broom is suspected to be caused by several different strains of mycoplasmas. It can reduce yields of marketable tubers from 10 to 80 percent depending on the severity of the infection. The plants become dwarfed and leaves turn a light green with reddish-yellow margins. Auxiliary buds on the main stem and branches grow, giving the vine an erect, bushy appearance. Plant stems are abnormally white and long, bearing numerous small tubers, often in chains, and a very few large tubers. Underground tubers send up premature, spindly sprouts at the base of old vines. It is not known how this disease is spread. The best control involves elimination of planting stock with hair-like, premature sprouts and roguing of plants with obvious symptoms.

3. Haywire, another mycoplasm caused disease is found in small amounts in the state and is of minor importance. Dwarfed plants emerge late and have a bunchy rosette appearance due to increased numbers of side shoots and shortened top growth. The leaflets are rough, stiff, erect, rolled, pointed, and slightly yellow. Infected seed pieces often produce small tubers rather than plants and diseased plants produce either no tubers or only a few close to the stem. This organism may be spread by insects, although it doesn't seem to be spread to any great extent through a field. The best control is roguing diseased plants.

F. VARIATIONS

Variations in a potato plant indicate that the plant has foliage or growth habits not normal for the variety, that is, any abnormality. Variations can be of commercial importance when they affect yield or time of plant maturity. Any change in appearance can cause a doubt of the plants identity.

1. Giant hill is one of the most important variations found in potatoes. These are off-type plants that mature much later than normal. This can cause serious problems with varieties that are grown for an early market.

   These plants have tall, vigorous stems, but they are fewer in number than healthy plants. They have many flowers that are conspicuous at full growth. The plants also remain green longer than normal plants. They appear resistant to late blight only because they become susceptible later in the season (two to three weeks) than normal plants. Yield may not be reduced much if the plants are allowed to mature but often there are fewer, rougher tubers than normal.

   The cause of this variation is not known. It seems to be carried by tubers but it is not known to spread to healthy plants. Some varieties are more prone to it than others. It is most common in northern areas with long periods of daylight during the growing season. The best control is roguing when normal plants are past their bloom and plants exhibiting giant hill are still blooming profusely.

2. Other variations include wildings, stitched end, and little leaf. None of these seem to be of much economic importance.

3. There are also some physiological disorders that affect potato production.

   a. Magnesium toxicity in highly acid soils can be cured by adequate use of lime. Magnesium deficiency can be cured by use of the proper fertilizer. Often symptoms that look like disease problems are caused by a deficiency or excess of important plant nutrients. This points to the importance of soil testing and proper fertilization.

   b. Poor storage can cause internal sprouting, some internal tuber rots, and black heart. Proper storage conditions will alleviate most of these problems. Correct temperature, relative humidity, ventiliation and oxygen balance should be maintained in storage facilities.

   c. Greened tubers can be a serious problem because they may cause solanine poisoning. The potato skin and occasionally part of the flesh turns green or a yellowish green due to exposure to sunlight or artificial light in storage. This usually results from shallow planting or improper hilling.

CHAPTER VII

DISEASES OF FORAGE CROPS

A. ALFALFA

Alfalfa is not only important in Montana as a forage crop, but it is also gaining importance as a profitable seed crop. Therefore, it is important to know what pests and diseases can cause loss on alfalfa in Montana.

1. Bacterial Diseases

a. Bacterial wilt (Croynebacterium insidiosum) is the most serious alfalfa disease in the United States. Any environmental conditions that favor rapid, vigorous crop growth will also favor rapid bacterial development. Generally, it is less important in hot, dry regions.

Infected plants are dwarfed and stands are reduced. Leaflets are smaller and thicker, yellowed, bleached, and tend to curl. There are excessive numbers of shortened stems produced, giving the stand a bunchy appearance. In advanced stages of infection, plants tend to wilt under hot, dry conditions. The roots show a yellow to brown ring under the bark when cut crosswise.

The bacteria overwinter in older, diseased plants or in soil water where they are released by plant tissue breakdown. Infection occurs during spring and early summer through wounds in plants, generally caused by injury during the previous winter. Bacteria spread through the xylem (water conducting tissue) in the root. Later in the summer this tissue becomes resistant to invasion. Once the plant is infected, the bacteria multiply, causing death of the plant usually by late summer of the second year of infection. These bacteria can be spread by mowers and through drainage and irrigation waters.

Control measures include proper management to prevent root injury which reduces bacterial spread. The best control method, however, involves use of resistant alfalfa varieties. There has been considerable work done in this area and there are good varieties available that combine many good agronomic traits.

b. Bacterial stem blight, caused by the bacterium Pseudomonas medicaginis, is of minor importance but it can cause some problems in local areas.

The bacterium forms lesions on the stems and foliage of younger plants. The infection can extend into the crown and roots of older plants. The lesions are linear, light to dark brown spots with droplets or scales of bacterial exudate. Generally, lesions are associated with frost cracks since bacterial infection is often found in conjunction with low temperatures and epidermal injury to the host plant. This disease is normally a problem in the spring on winter injured plants.

2. Fungal Diseases

a. Alfalfa leaf spot is caused by two closely related species of fungi, Pseudopeziza medicaginis (common leaf spot) and P. jonesii (yellow leaf blotch). Common leaf spot is most often found in Montana. A light infection is not usually too important, but severe infections can cause defoliation.

Common leaf spot forms small, brown spots on leaflets which do not coalesce or discolor the surrounding tissue. Small black dots, the fungal fruiting bodies (apothecia), form in the center of the spots. Spots are rarely found on stems, and then they do not form apothecia. A heavy infection can cause defoliation.

Yellow leaf blotch is less widely distributed. Young lesions form yellow stripes and blotches parallel to the leaf veins. As these lesions enlarge, the color changes to orange-yellow or brown, shading to yellow on the margins. Orange-brown pycnidia are formed on the upper leaf surface. Apothecia are usually formed only after leaves drop off the plant. Stem lesions are rare but when they do form, they are dark brown in color and produce apothecia.

The fungi overwinters as apothecia on leaves that have fallen. In the spring, ascospores form continually from infected plant debris, therefore, inoculum is abundant throughout the entire growing season. Yellow leaf blotch inoculum generally lessens as the season progresses.

Control measures include cutting the crop prior to leaf drop and destruction of waste plants as a source of inoculum. Some varieties, resistant to common leaf spot, are available and may be used under irrigated conditions.

b. Crown wart (Urophlyctis alfalfae) is a fungal disease that occurs primarily in warmer areas. It is generally confined to local wet areas of a field such as bottom lands where a lot of moisture is available.

The fungus causes large, knobby swellings in the crown and roots. Young galls are usually white and as they decay, they change to gray and then to brown. By mid-summer, they have dried up. The plant becomes stunted, unthrifty, and often dies. The swollen cells of the gall tissue contain the resting spores of the fungus. These spores are also soil-borne and can persist indefinitely as oospores. Therefore, inoculum is usually present and infection occurs under favorable conditions. The best control measure is soil drainage where areas are unusually wet.

c. Alfalfa black stem can be a severe problem under cold, wet conditions. It is caused by a fungal complex of Asochyta imperfecta, A. meliloti, and Phoma trifolii.

Dark brown to black, small, irregular lesions are formed on stems and petioles and severe infections on young stems and shoots can cause girdling and death. The brown spots formed usually coalesce and form blackened areas. Infected leaves turn yellow, wither, and drop. Often under cool conditions, pods also have lesions formed on them.

The fungi persist in crop refuse on the soil surface. Pycnidia develop abundantly on stems in late fall and early spring. Under favorable conditions, the spores infect plants through natural openings or wounds. Crown or root infections cause alfalfa rot and in areas where conditions favor pod infection, the disease can also be seed borne.

Effective control measures include crop management and use of adapted resistant varieties. Since the fungi only persist in crop residue for a year, crop rotation can be effective in controlling black stem. When pods are infected, seed treatment should be used.

d. Verticillium wilt (Verticillium albo-atrum) affects the water-conducting tissue which leads to chlorosis and dessication of the leaves and stems. Typically, U-shaped segments of the leaf tip turn a tan to copper color with all the leaves and then the stems dying. Only part of a plant may be affected at any one time. Roots of infected plants show internal brown streaks or general brown discoloration in the upper portion. Thus far, this disease has not been confirmed in Montana.

The presence of anthracnose (Colletotrichum trifolii) is indicated by the appearance of scattered, dead, straw-colored shoots with recurved tips resembling shepherd's crooks. Stem lesions and/or crown discoloration and rotting may also be caused by this fungus. The disease weakens the plant and results in stand loss. Resistant varieties are available.

e. Phytophtora root rot (P. megasperma) can cause plant losses in seedling or older stands where overwatering occurs or where soils are poorly drained. It is not ordinarily a problem in light, well-drained soils. Roots develop yellow to black lesions and rot off at various depths. The plant top is stunted with yellowed or slightly red leaves. If sufficient top root remains when the soil dries, plants may initiate lateral roots and survive. Resistant varieties are available.

Under cool, moist conditions, downy mildew (Peronospora trifoliorum) has been observed to kill seedling alfalfa in the field and can reduce yield in established plants. Infection results in light green to yellowish leaf blotches or entire leaves and shoots may have downy mildew. Resistant varieties are available.

3. Virus Diseases

a. Alfalfa mosaic virus is important on alfalfa, beans, peas, potatoes, celery, and pepper. It can be transmitted mechanically and by several different aphids.

Leaves develop small green-yellow spots and later more extensive and diffuse chlorosis appears. Leaflets are crinkled and irregular in shape, but there is no tissue necrosis. High temperatures tend to mask disease symptoms. Infection rate seems greater by aphid transmission than by mechanical and the virus persists in crown tissue.

The best control for virus diseases involves use of virus free planting stock, control of alternate hosts, and control of insect vectors. It isn't a good idea to grow alfalfa closely following a crop that is also a host of the virus, especially if you know that crop was infected.

b. Alfalfa dwarf virus can be serious in limited areas. It is transmissible by amblycephalinae leafhoppers. The plants become dark green and dwarfed. Plant vigor declines over several seasons, resulting in eventual death. A brown gum-like material is deposited in the xylem bundles of roots. The disease is most prevalent under high moisture conditions. The virus has a wide host range and can also be transmitted by grafting. Control is achieved by control of the leafhopper, careful grafting, and use of virus free stock.

c. Wound tumor virus is a widely distributed virus of minor importance. It is also called clover big vein. The disease is transmitted by leafhoppers. The virus causes swelling or tumor formation in phloem tissue after it is punctured by a viruliferous leafhopper.

4. Mycoplamsa Diseases

a. Aster yellow disease is caused by a mycoplasma and transmitted by leafhoppers. It causes stunting and excess branching. Flowers become chlorotic, malformed, and sterile but remain on the plant. Some mycoplasmas can be controlled with antibiotics and control of the vector can also be effective in limiting the disease spread.

b. Witches broom is another mycoplasma caused disease and is transmitted by grafting, dodder, and leafhoppers. This can be a serious disease in local areas. The infected plant develops crown buds that form fine stems that exhibit marginal chlorosis and crinkling. Flower buds develop poorly. Infected plants show relatively short-lived symptoms each season. There is a long incubation period associated with leafhopper transmission, therefore, annual legumes are an unlikely host.

5. Nematode Pests

a. The alfalfa stem nematode (*Ditylenchus dispaci*) occurs widely in irrigated central Washington. It has been found in low populations in isolated Montana fields. The nematode feeds and reproduces mainly in the base of stems and in crown buds. Cool, moist weather of spring and fall favor nematode development and symptom expression. Swollen, wrinkled crown buds, thickened stems with shortened internodes, and white but turgid stems and leaves ("white flag") in regrowth are symptoms of the nematode's presence. Yield losses of up to 25 percent by the second year are reported. Control consists of rotation with a non-susceptible crop, such as small grain, and planting resistant alfalfa.

b. The root-knot nematode (Meloidogyne hapla) infects alfalfa and is a major drawback to the use of this crop in rotation with potatoes and sugarbeets. The root-knot nematode is most important in stand establishment. As much as 30 percent kill of seedlings have been observed. Once established, alfalfa seems to tolerate root-knot infestation. Typical symptoms this nematode produces are round swellings or galls on feeder roots. Most practical means of control is by rotation with a small grain kept free of weeds and volunteer alfalfa. An alfalfa variety resistant to the root-knot nematode is being tested.

c. Root-lesion nematodes (Pratylenchus spp.) occur widely throughout central Washington and infect many crops including small grains, mint, and potatoes, as well as alfalfa. Greenhouse experiments have shown that the root-lesion nematode, Pratylenchus penetrans, can reduce alfalfa growth, but the nature and degree of damage in the field is unknown. Roots infected with this nematode usually are darker in color, with fewer feeder roots than uninfected plants.

B. SAINFOIN DISEASES

1. Root, stem, and crown rot is a disease caused by the fungus Sclerotinia trifoliorum. It causes all the stems in one clump to wither and turn brown in the middle of the growing season. Under moist conditions, small white to tan wefts of mycelium are found on the outer stem near the soil line. Small, hard, black masses of mycelium (sclerotia) are formed and the fungus overwinters in the soil in this form. In the spring, these sclerotia germinate and develop spores that are wind blown to developing plants. This pathogen is not usually a serious problem in Montana and can be controlled by rotation with non-susceptible crops such as cereal grain. Red clover is an alternate host for the fungus and is, therefore, a potential source of inoculum.

2. There are several fungi that cause leaf spotting on sainfoin. Septoria orobina forms round, fawn colored spots up to 6 mm in diameter with a distinct brown margin. Small black dots (pycnidia) found in the spots are usually fairly characteristic of Septoria. This fungus can also attack seed pods so seeds are an important source of dissemination. Ramularia onobrychidis is another leaf spot fungus. The initial leaf spots are dark brown. They grow paler in the center with age, thus resulting in a ring spot appearance. The older, greyish spots form sclerotial bodies. This leaf spot disease is most severe under moist conditions. Another ring spot is caused by Pleospora herbarium (imperfect stage of Stemphyllium botryosum). This leaf spot resembels Septoria and under moist conditions, the production of dark conidia gives the leaf a sooty appearance. All of these leaf spots are best controlled by use of a regular crop rotation schedule. None of these pathogens have been observed in Montana.

3. Aschochyta onobrychidis causes a leaf and stem spot on sainfoin. In Montana, symptoms are generally irregular blackened stem lesions with pycnidia embedded in them. The organism is seed borne and seems to persist in crop residue. At this time, the disease doesn't seem to be too damaging in the state.

4. Verticillium wilt (V. albo-atrum) can cause problems in sainfoin and during hot periods, infected plants may show a flaccid wilt. The leaflets of outer leaves that are infected turn pale, tending to fold upwards along the mid rib. Eventually, the leaves turn yellow to brown and die. The vascular system of the plant becomes discolored affecting roots, stems, and leaf petioles. The most effective control is a reduction of soil water content and a long crop rotation schedule. This fungus has never been found in Montana.

5. Often root rot organisms (Fusarium sp. plus several bacteria) are found attacking older plants. This causes a dry, brown rot of the inner tissue of the tap root. Attack of the plant by these organisms will weaken it and decreases the winter survival capacity.

6. Other organisms that can be found attacking sainfoin include Uramyces onobrychidis (rust) Botrytis conerea (chocolate spot) that attacks the flower bud; Erysiphe polygoni, powdery mildew; and a stem and bulb nematode, Ditylenchus dipsaci. There have been no reports of bacterial or viral diseases on sainfoin.

CHAPTER VIII

DISEASES OF FRUIT TREES

A. STONE FRUITS

1. Fungal Diseases

a. Cherry leaf spot is found on both sweet and sour cherries. This fungus, *Coccomyces hiemalis*, infects mature leaves, as they are more susceptible than younger leaves. It can cause partial to complete defoliation. Early season leaf loss causes production of small, unevenly ripened fruit; severe infections weaken the trees, increasing chances of winter kill. Generally, winter injury is limited to killing buds, shoots, and fruit spurs, resulting in poor crops the following season.

Infected leaves form small, purplish spots that later turn brown. These spots enlarge and may merge into very large, irregular areas. These areas become corky and may drop out, giving the leaf a shot-hole appearance. During wet periods, a whitish spore mass is found on the underside of the leaf. Badly infected leaves turn yellow and drop off. The yellowing and leaf drop generally follow a wet period so there may be several cycles of defoliation in one growing season. Long rainy periods result in severe infections which can affect the fruit, stems, and leaf petioles, as well as the leaves.

The fungus overwinters on fallen leaves in apothecia. In the spring, ascospores are discharged and drift in the wind onto new leaves. Newly infected leaves produce conidia that are carried by the wind and rain to infect other leaves. Infection increases under favorable environmental conditions as the season progresses.

Primary control of cherry leaf spot is through use of protective fungicides under an effective spray program. Supplemental sanitation, raking, burning, and cultivation during blooming aids in destruction of inoculum and results in less favorable infection conditions. Certain varieties, including pollinators used in sweet cherry production, are more susceptible and should be avoided when possible.

b. Silver leaf is a disease caused by the fungus *Stereum purpureum*. It can easily be confused with a condition found on healthy plants that is caused by overfertilization. This overfertilization is not a serious problem, but the fungal infection can become very serious. This makes diagnosis of the problem inportant. The fungus is a weak parasite that infects many species of woody plants including cheeries, apples, plums, apricots, peaches, mountain ash, and rose. Plants that have low vigor or winter injury are most susceptible to infection.

The first noticeable symptom is a metallic, silvery discoloration on the leaves due to air pocket formation between the upper epidermis and palisade parenchyma. The fungus is found in discolored heartwood of diseased branches, often quite a distance from the silvered leave The affected plant parts lose vigor over a period of time, often staying alive and unthrifty for several years. Infected trees will eventually die.

This is a wound parasite so the fungus can only infect a tree that has a fresh wound. Some soil spread occurs, but only through root grafting. The fungus usually infects the heartwood, grows through the vessels, finally entering the sapwood. Heaviest spore production occurs during rainy months. Fruiting bodies with spores are produced on the bark once the fungus permeates the sapwood. Winter injury and excessive moisture are predisposing factors for infection. The disease is found mainly in cool, humid climates.

Slightly infected trees may recover. Pruning and burning of diseased areas and then covering the wound with grafting wax of Bordeaux paste will aid in slowing the disease spread. It is important to avoid large pruning wounds; if the infected area is too large, the tree should be taken out. Diseased trees should also not be overwatered. The best control measure for this disease is to maintain a healthy, well managed orchard, since healthy, vigorous trees are less susceptible to silver leaf.

c. Powdery mildew, caused by the fungus Podosphaera oxyacanthae on cherry (Sphaerotheca pannosa on peach), can be an important disease in nursery stock.

Young leaves are most susceptible. They tend to roll upward and have a decreased terminal leaf size when infected. Often this is accompanied by shortened twig growth. The underside of the curled leaves are covered with a white felt-like mycelial growth. The powdery coat, typical to powdery mildews, is caused by production of conidia. Later in the infection, there are black specks (perithecia) found in the white mass.

The fungus overwinters as perithecia on fallen leaves. Ascospores are released in the spring, causing initial infection. Secondary infection occurs throughout the season from conidial production on leaf surfaces. Spore germination is favored by hot, dry weather between periods of high humidity or early morning dew.

Control measures are only necessary if powdery mildew looks like it is building up to economic conditions. There are several protective fungicides registered for use.

d. Dibotryon morbosum, causal agent of black knot, produces black warty growths on trees. It is of minor importance in well managed orchards but it can be a problem in home orchards that are not on a regular spray program. Bearing capacity of infected trees is reduced due to heavy pruning, which is a recommended control.

Susceptible hosts develop elongated swellings or knots that start ou a greenish color and soon grow darker. By fall they are coal black and hard. Knots continue to grow and often fuse until an entire branch is girdled and dies. After several years, the tree becomes worthless because of limb death, stunting, and secondary invasion by insects and wood rotting organisms.

Perithecia are produced on the surface of knots that are one to two years old. Spores produced are discharged during periods of rainfall and carried by wind or rain to infection sites. Usually spore discharge and infection is most severe one to three weeks after bloom, but is can continue until terminal growth stops. Spores infect the host directly through the unwounded surface and infection is most severe under wet conditions when the temperature is between 55 and 70°F. After infection occurs, there is a period of several months before knots appear. The knots can appear anytime from late fall of the first year to early spring of the next. Old knots continue to grow in the spring and fall months until branches are girdled and die.

There are some fungicides for use against black knot, but they are only effective when used in conjunction with good sanitation practices. Wild hosts, especially plums and seedling cherries, should be removed. The fungus usually extends beyond the swelling so pruning cuts should be made well below the visible infection. Removed parts should be burned to destroy inoculum.

e. Armillaria root rot is caused by the mushroom producing fungus Armillaria mellea. Infestation can eliminate otherwise good orchard sites from production. It can be important on all fruit crops.

Early symptoms are fairly vague. There is a general decline or weak appearance of the infected tree. Foliage is a light yellow, poor growth occurs, and often the leaves change color early in the fall. There is reduced terminal growth and premature defoliation. In advanced stages, the disease causes dieback of branches or even the entire tree. A fungal mat often occurs between the bark and wood in the cambium. The roots may have large dead areas near the crown root with long, black, string-like rhizomorphs attached. These rhizomorphs spread the disease from tree to tree. The final evidence of infection is the appearance of honey-colored mushrooms around the base of the tree. These only appear when most of the roots have already been destroyed.

The fungus survives for several years as rhizomorphs and mycelial strands in infected root fragments, waiting for a susceptible host. They can penetrate a living root when it comes into contact with one.

There are no economical controls available for this disease. The fungus is often found in forested areas, so newly cleared land should be planted with row crops several years prior to planting stone or pome fruits. Infected plants should be entirely removed, including roots, and burned. Fumigation is possible but this is very expensive and difficult to do effectively since the fungus can persist for so long and so deeply in the soil.

f. Brown rot is an important fungal disease of stone fruits in the field and storage. It is most serious in cool, wet regions. European brown rot is caused by Monilinia laxa and American brown rot is caused by M. fruiticola. These fungi can cause both blossom blight and fruit destruction. Symptoms can develop on blossoms, spurs, shoots, and fruits. Infected blossoms wilt, turn brown, and persist on the spur into the summer. The fungus can then move onto the spur and, in the case of European brown rot, down blighted twigs to branches. Cankers are formed that can girdle the twigs and branches, causing terminal growth to wither. Gummosis may also occur.

Fruit rot is the most noticeable phase of the disease. Green fruit may be infected but heavy infection is most likely as fruit nears maturity. Infection starts as small, circular, light brown spots on the fruit surface. It spreads rapidly under favorable conditions and can destroy the whole fruit in a few hours. The rotted fruit then either falls to the ground or hangs in the tree as a mummy. Conidia are produced, whenever the weather is humid, from sporodochia found on the lesions. These spordochia are characteristic of brown rot.

The fungus overwinters as sporodochia or mycelium in all infected plant parts, especially mummified fruit. In the spring, apothecia are produced in the ground on overwintering fruit. These apothecia are of minor importance and usually only found associated with American brown rot. Apothecia develop when moisture is available and temperatures are 63 to 68°F. Wetted ascospores are forcibly ejected from asci and carried by wind and rain to blossoms.

Conidia form from early spring on, when the relative humidity is greater than or equal to 85% and temperatures aren't too hot. These conidia form on mummified fruit and canker surfaces. They are carried by splashing rain or wind primarily, and somewhat by the plum curculio. The fungus can infect the host directly through natural openings or through wounds. Environmental conditions are very important to disease build-up. In warm, humid weather, fruit rot and spore production are greatly increased.

Removal of all fruit, mummies, and blighted twigs from trees after the last picking greatly aids in reduction of inoculum. Cultivation of trash in the spring will help destory apothecia. Spray applications of fungicides should be timed with blossom bud or fruit development and climatic conditions. A combination of spring, preharvest, and postharvest fungicidal applications should help control brown rot.

2. Bacterial Diseases

a. Crown gall is not usually a serious problem because infected plants are culled from nursery stock prior to sale. It is a disease caused by the bacterium Agrobacterium tumifaciens.

The disease is characterized by the formation of galls or tumors from ¼ to 3 or 4 inches in diameter. Usually these galls are found on the roots or crown, but may occasionally develop on aerial portions of the plant. The galls have gnarled surfaces that darken with age. Plants with numerous or large galls that girdle the stem or root may become stunted or sickly with small red or yellow leaves.

The bacterium is widely distributed and survives well in the soil. It enters the plant roots through wounds, which makes it important in nurseries where the plants may be wounded by budding or grafting. Other mechanical injury to the crown or roots by cultivation equipment, animals or insects can cause points of entry for infection. There is often secondary tumor formation in distant parts of infected plants where no bacteria are associated with the formation. The mechanism involved in not totally understood but it is referred to as the tumor-inducing principle (TIP).

Primary control of crown gall involves prevention of bacterial spread. This can be done through crop rotation, elimination of suspect nursery stock, sterilization of grafting implements, and fumigation (practical only at the nursery level).

Biological control products are now available for control of crown gall disease in fruit and nut trees. These products are made up of a highly competitive non-pathogenic strain of A. radiobacter, which prevents crown gall on young nursery stock through ecological exclusion.

b. Bacterial canker can cause problems on cherries as well as on peaches and plums. It is caused by a combination of Pseudomonas syringae and P. morsprunorum.

The bacteria attack almost all plant parts. Branches and twigs are cankered with a heavy exudate of gum associated with them. Severely cankered branches may wilt and die in the summer or early fall from girdling.

Leaf and fruit infections are most important during periods of prolonged wet, cool weather after bloom. Infected leaves develop dead areas which can drop out, leaving a tattered leaf. Severely infected leaves fall prematurely. Infected fruit and stems may develop deep, black depressions that are susceptible to a secondary invasion of brown rot. Infected leaf and flower buds may be killed while dormant and fail to open in the spring. Diseased buds may develop small cankers at the base. Spurs may open normally but collapse later in early summer, leaving wilted leaves and dried fruit.

The bacteria overwinter in cankers, infected buds, and possibly systemically in apparently healthy tissue. Infection occurs in the fall through leaf scars and in the spring through bud scale scars. In the spring, the bacteria are disseminated by the washing action of rain on emerging tissue. Developing blossoms, leaves, and fruit are infected through natural openings as well as wounds, especially on those trees injured by frost. Secondary spread of the bacteria from the initial infection sites is important in disease buildup.

Ideal conditions for bacterial infection are found in the spring and fall when there are cool temperatures and high winds accompanied by frequent rainfall. During the summer when leaves are less susceptible and temperatures are high, bacterial activity is greatly diminished.

Little is known about effective control measures for bacterial canker. There are some protective sprays available and cankerous areas should be removed.

3. Mycoplasma Diseases

a. Western X or buckskin disease of stone fruits is caused by a mycoplasma and can be found on most commercial stone fruits as well as wild chokecherry.

X disease symptoms are similar to nitrogen deficiency, bacterial spots, winter injury, peach tree borer, and some mechanical injury. All of these can be confused, but if chokecherries are found within 500 feet of an orchard, the trees are probably infected with the mycoplasma. Leaves of isolated branches tend to curl inward, usually from mid-June to July. They develop water-soaked spots which become yellow to reddish-purple. These discolored areas drop out, leaving a tattered appearance. Affected leaves fall prematurely, leaving only a tuft of leaves at the tip of the stem. Within two or three years after the initial infection, all branches of the tree show symptoms. Infected cherries ripen unevenly, producing small, immatu cherries with an insipid flavor. Fruit on infected trees is worthless and diseased trees will usually winter kill after a few years.

Spread of the mycoplasma is associated with leafhopper transmission. Usually the insect vector prefers wild hosts and is blown or strays onto a cultivated orchard. The best control available involves eradication of all chokecherries within 500 feet of a commercial orchard. There is work being done on chemical suppression or control.

4. Virus Diseases

a. Little cherry is a virus disease of sweet cherries that can spread rapidly once it is found in an area. Infected cherries are not suitable for either fresh fruit trade or processing purposes. It is economically impractical to produce cherries where this disease has become established.

There are no early season symptoms of this disease. Symptoms on fruit become apparent seven to ten days prior to full maturity and are best observed at full maturity. Fruit size varies depending on the severity of the disease, amount of fruit set in relation to foliage, cultural care, and general growing conditions. Tree variety also affects the amount and severity of the disease; Lambert and Republican are very susceptible while Bing, Black Tartarian, Deacon, and Napolean are moderately susceptible. Affected fruit is about half the size of normal and more pointed. They also usually retain the coloring of immature cherries. All fruit affected by the virus lacks sweetness and flavor. Leaves with severe virus infection become apparent only after harvest. The leaves are faded with a yellowish-green cast, later they turn light brown to bronze. Some trees also show bud scale separation that results in a frayed appearance.

The virus spreads rapidly once it is established. It has no known insect vectors but can be transmitted by budding and grafting. The best control is use of virus-free nursery stock and destruction of infected trees.

b. Small bitter cherry disease is a viral disease found only on Bing cherries. It is of minor economic importance but can be confused with little cherry virus. The symptoms are confined to the fruit and detection and diagnosis is only possible during harvest. Normal cherries and small cherries occur on the same trees but never on the same branches. Normal looking fruit is of good quality, while small fruit is bitter and objectionable. The disease spreads slowly and mode of transmission is not known.

c. Twisted leaf virus on sweet cherry can be easily diagnosed when three characteristic symptoms are found together. First, leaves have bilateral inequality with the smaller side more chlorotic and with acute angles. Plant parts are distorted, the leaf tips tend to bend down abruptly, petioles are bent and twisted, and leaf margins are wavy and somewhat buckled. Last, leaves exhibit necrosis, generally along the midrib as it extends upward. Often this area will fall out. Other sumptoms include stunting of infected leaves and stunting of trees, and shortened internodes, especially of lateral branches, under severe infection. There are no striking fruit symptoms. The disease is transmitted by budding and grafting. There are no known insect vectors.

d. Sour cherry yellows is a viral disease of sour cherries that increases slowly and, since initial losses aren't spectacular, it is often overlooked. Yield losses increase with time.

The leaf symptoms show a characteristic mottling and yellowing, followed by heavy leaf drop. Defoliation usually occurs in waves beginning three to four weeks after petal fall. Severity of defoliation depends on temperature, low temperatures increase later symptom development. Flower buds develop excessively on lateral and terminal shoots, giving a willowy type growth with long bare spaces. Flower buds are weaker and abnormally sensitive to low temperature. The bloom is staggered giving rise to uneven fruit development and ripening. Trees develop larger fruit than normal.

The disease is possibly caused by a viral complex and it seems to be transmitted through pollen. To control the virus, it is important to use virus-free stock. Once a tree is infected, there is no control available. Trees should be planted in solid blocks and infected areas should be kept until they are no longer profitable. Then the entire block should be removed and replanted.

e. Necrotic ring spot is a virus disease that only causes losses to yield in years when symptoms appear. The virus can be latent one year, causing no damage, and then produce an acute or "shock" stage of the disease the next year, causing great yield reductions.

In years that symptoms occur, the leaves are smaller than normal with light green spots and dark rings or partial rings around them. The spots are 1/16 to 1/4 inches in diameter and may die and fall out of the leaf. Affected leaves are often rough and pebbly. There is some stunting and dieback of the tree.

The virus is usually transmitted into young plants through pollen, therefore, heavy bloom is the time of greatest infection. The rate of spread and buildup of the disease is dependent on the proximity of young stock to older, infected trees. Once a tree is infected, it can take from a few weeks to two years to develop symptoms. Severity of symptoms are temperature dependent, leaf symptoms occur from 68 to 75°F. and dieback occurs at higher temperatures. The only effective control is use of virus-free stock. Virus indexing has been very useful in the control of this disease.

f. Green ring mottle is a virus disease found primarily in older orchards that were planted prior to the use of virus indexing. It is very similar to yellows disease but shows prominent dark green blotches or rings in the yellow area. Leaf symptoms occur in waves from late June to mid-July. Defoliation isn't usually too severe. Often a constricting chlorosis along the lateral vein and a slight leaf tip distortion is obvious prior to the yellowing symptoms. There is little known about the spread of this virus. It has been found in some weed hosts but no one is sure if they are involved in transmission. Some spread occurs from propagating material. Use of virus-free stock will help control this disease.

Since the introduction of virus indexing, losses to fruit trees due to viruses have greatly declined. It is an important tool in management of healthy, productive orchards.

B. POME FRUITS

1. Bacterial Diseases

a. Fire blight is a bacterial disease that is widespread on species of the rose family. The name is derived from the appearance of badly infected terminal branches that look burned or scorched. It is most economically important on apples and pears since extensive pruning of branches for control interferes with future reproduction of fruit.

Erwinia amylovora, causal agent of fire blight, attacks any part of the tree from roots to leaves. It usually appears in the spring as a blossom, spur, or terminal shoot blight. Infected blossoms suddenly wilt and turn soaked and dark green with pearly or amber colored exudate droplets appearing on the surface of infected tissue. Blighted leaves remain attached for the season and early infected terminal shoots often bend into a characteristic shepherds crook, turning brown to black. The bacteria usually move down the spur or terminal shoot into branches where cankers can form, girdling the branch and spreading the infection up and down the branch. The entire scaffold may be systemically destroyed and conformation ruined. Bacterial movement is eventually restricted by slowing growth or maturity of infected tissue.

Infected fruit has a water-soaked look and they exude droplets of bacteria ooze. The diseased fruit is firm and later becomes leathery. They eventually shrivel and turn brown, remaining attached to the spur.

The bacteria overwinters in living host tissue along the margins of cankers on large branches. In the spring, about late pink to early bloom in the tree, milky white or cream colored droplets ooze from the canker margins with large numbers of highly infective bacteria. These bacteria are spread to susceptible blossoms and young leaves by wind blown rain and insects. Bacteria enter through natural openings or injuries. Optimum temperature for development is 76°F. and after an incubation period of four to five days, symptoms appear. Soon after an ooze again appears providing a source of secondary inoculum.

Bacterial diseases are expensive and difficult to control. Any control measure must be initiated prior to infection. Effective orchard management, use of sanitation methods, resistant varieties, and chemicals can help cut losses from fire blight. Any practices that initiate rapid growth when infection is most likely should be avoided. Since pears are more susceptible, they should not be planted near apples. There is no immunity to fire blight known but some resistance is found in Delicious, Dolgo Crab, Duchess, Florence, Crab, Gano, Haralson, Hibernal, Jonathan, McIntosh, and No Spy apple varieties.

Key control is removal of infected branches or trees. They should be pruned when the disease is first noticed, 10 to 12 inches below the point of visible infection. Cutting knives should be sterilized between each cut. Branches can also be removed in late summer when blighted leaves are still obvious.

Control of insects during bloom can help reduce insect transmission of the bacteria. Chemical control includes use of streptomycin sulfates, copper, zinebs, or Bordeaux mixture. These can cause some foliar damage, expecially Bordeaux, so they should be used with caution. Even with available control measures, the disease cannot be eliminated because of the many wild hosts and disease organisms carried from other orchards.

2. Fungal Diseases

a. Apple scab is one of the most commonly occurring apple diseases. The fungus *Venturia inequalis* attacks leaves, petioles, shoots, blossoms, and fruit; however, the most striking symptoms are found on the leaves and fruit. Leaves are usually infected as the leaf bud opens. Once the entire leaf is unfolded, both sides develop lesions on them. Initially, the lesions are inconspicuous, dull, smoky areas on the leaves; later, they become olive-colored and velvety, turning darker with age. Diseased leaves are distorted and a severe infection can cause dwarfing and defoliation. Fruit infection usually starts on the sepals and moves onto the fruit as it develops. The lesions developed are similar but they become brown and corky with age. Early fruit infections result in uneven growth from the caylx end and cracking of the skin and flesh. If fruit are infected in late summer or early fall, the fungus usually develops rough, black,circular lesions on the fruit in storage.

The fungus overwinters on the orchard floor on leaves that have fallen. Usually perithecia are produced on these leaves in late fall or early spring when alternating periods of wet and dry weather occur. Ascospores are produced in the spring and are the source of primary inoculum. Ascospore formation is favored by wet, warm spring weather. Dry springs tend to delay development. Mature spores are ejected when they are wetted and wind borne onto emerging plant tissue. This usually occurs about the same time as blossom buds begin to open. Primary spore production usually takes five to nine weeks for all maturation and discharge to occur. The spore requires a film of water for germination and usually germinates as soon as it hits the plant tissue. Temperature and humidity determine the infection severity. The first lesions usually occur within nine to seventeen days, producing conidia that are the source of secondary infection and disease build up and spread. Conidia production and infection is favored by high humidity and moderately high temperatures. Free water and especially splashing rain is important for detaching and spreading the conidia but not necessarily for spore germination. Heavy production of secondary inoculum late in the fall is important as an infection source for stored fruit and build up on leaves that can lead to production of heavy primary inoculum the following spring.

A good method of control for apple scab is through use of an effective spray program. Protective fungicides are used to prevent spore germination and penetration; eradicant fungicides can halt fungal growth after the infection process has started; or these two can be used in combination for effective control. Systemic chemicals interrupt the fungus lift cycle, thus suppression spore production and secondary spread. Protective chemical applications should be applied periodically at predetermined intervals that are dependent on environmental conditions. Eradicant fungicides have a more specific temperature requirement and are usually effective for only a few hours or days.

Resistant varieties are available and provide good control of apple scab. Good resistance can be found in Jonathan, Spartan, Yellow Delicious and Yellow Transparent apples. McIntosh and Red Delicious are Montana's most susceptible varieties.

Control of overwintering perithecia can aid in reduction of apple scab inoculum. A fall application of nitrogen hastens leaf decomposition leaving fewer places for perithecia to form. There are some post harvest fungicides that will inhibit perithecial formation but these are not commonly used.

b. There are several rusts that are found on apples. These include cedar-apple rust (Gymnosporangium juniperi-virginianae), quince rust (G. clavipes), and hawthorn rust (G. globosum). All of these fungi have red cedar as an alternate host. Quince rust is destructive to fruit, hawthorn to foliage, and cedar-apple rust to both foliage and fruit.

Cedar-apple rust and hawthorn rust have similar symptoms and life cycles. Orange lesions are formed on the fruit and small cup-like structures form on the surface when mature. Leaves develop bright orange lesions. The red cedar stage of the disease develops reddish brown galls on the cedar that are ¼ to ½ inches in diameter. The galls have depressions on the surface that develop yellow gelatinous (or telial) horns during rainy periods.

Quince rust forms dark green, sunken lesions on the apple fruit. The tissue below the spots is killed and no cup-like structures are formed. There are no galls formed on the cedar host, telial horns are cushion-shaped, and red gelatinous masses form that lose shape and color as spores mature and are discharged.

These fungi are obligate parasites that will only attack apple and red cedar and require two years to complete their life cycle. Aeciospores from apples are dispersed in July and August and can only infect red cedar in the area. By the end of the second year after infection, the cedar "apples" or galls have formed and produce and discharge teliospores during the second spring, following wet periods. These two-celled teliospores germinate, producing eight basidiospores which can infect nearby apple trees in May and June. Lesions are formed on the apples in one to three weeks, developing pycnidia on the upper leaf surface as secondary inoculum and aecia on the lower leaf surface later in the season.

Control involves a combination of alternate host removal and fungicide application. Removal of red cedars within a two mile radius helps to interrupt the life cycle of the fungus. This aids when fungicides are applied periodically from the pink stage of bud development to third cover. The plant becomes fairly resistant to infection after petal fall.

c. Powdery mildew of apple, caused by the fungus Podosphaera leucotricha. causes loss primarily due to stunting. It can be a serious problem in nurseries where it interferes with the quality of tree production. Most loss occurs when the fungus has built to high levels and infects young shoots, leaves, buds, blossoms, and fruit.

Leaves develop whitish felt-like patches of fungal mycelium and spores on the underside and along margins. Lesions spread rapidly, engulfing the entire leaf. Infected leaves are narrow, folded longitudinally and become stiff and brittle with age. Severe infection can cause defoliation. Blossom buds that were infected in the fall open later than usual the following spring or can be killed outright by low winter temperatures. Flower parts and leaves are covered with mycelium as they emerge. Shoots are shorter and stunted. Frui rarely becomes infected unless the disease has built to high levels, then fruit can become russetted and often dwarfed.

The fungus overwinters in buds that were infected the previous season. As infected leaf buds grow, the fungus becomes established and produces chained conidia. These conidia are carried by wind to new tissue to initiate secondary infections. Spores require high relative humidity and 60 to 80°F. temperatures to germinate. They then invade host tissue by sending haustoria into epidermal cells. Secondary cycles continue until tree growth stops in late summer. Perithecia may be formed in late summer but ascospores probably do not overwinter and aren't important in the spring for primary infection.

The best control measure is use of an effective fungicide from pre-pink to third cover. Pruning may be helpful but isn't too practical on a large scale.

d. *Sooty blotch* and *fly speck* are two fungal diseases of apple that are usually found together on fruit. Caused by the fungi *Gloeodes pomigena* and *Microthyriella rubi* respectively, they rarely cause much real damage to the fruit, but lower the market value due to cosmetic damage. Because of regular spraying programs in commercial orchards, these fungi are usually found only in backyard plantings or in poorly managed orchards.

The fungi infect apples as well as many related wild hosts. The symptoms are superficial. Sooty blotch forms brown to olive green lesions that can be rubbed off. Fly speck produces sharply defined black shiny dots in groups of 10 to 20 specks.

Both fungi overwinter on infected twigs. The conidia are wind blown from pycnidia on infected hosts from June to September. The disease development is favored by moderate temperatures and high humidity. These diseases are easily controlled by fungicides applied for control of other, more important pathogens.

CHAPTER IX

DISEASES OF SUGAR BEETS

A. FUNGAL DISEASES

1. Cercospora leafspot is a disease caused by the fungus Cercospora beticola. It is distributed world-wide on many closely related species of sugar beets.

   Infected plants have small brown flecks with reddish-purple borders. Older lesions become ashen-grey with the border remaining purple. Mature spots are thin and brittle and the center drops out. A sudden change from cool to warm weather causes more severe problems; if it is very severe, the foliage is killed, starting near the plant base. If several crops of leaves are killed, the roots become elongated and roughened (called "Pineapple Disease"). Lesions can also occur on perioles, flowers, pedicels, and roots.

   The fungus overwinters on diseased plant refuse or on seeds. In the spring, the mycelium grows and produces spores on leaves in the soil, furnishing inoculum for the next beet crop. The fungal spores are disseminated by splashing water, insects, tools, man, and wind. Infection can occur through stomata, therefore, it is most common on mature leaves. Spores require about a six day incubation period (longer in cooler temperatures). Optimum temperatures for spore germination is 75-80°F. and 80-85°F. for host penetration.

   The best control is by utilizing resistant beet varieties. Maintenance of good plant growing conditions, crop rotation, and plowing under of plant debris also helps control this disease. Fungicides may be used when conditions warrant their use.

2. Black rot of sugar beets is caused by the fungus Aphanomyces cochliodis. It is a type of water mold and is especially important in areas of saturated soil.

   It causes damping off of young plants in areas with very wet soil. In drier soil, tap roots are infected as they go deep into the soil for moisture. The root tips turn black and the outer tissue sloughs off. Infection can also start at the side of the root and girdle it. Leaves wilt and turn yellow. A serious infection can kill the entire plant and a less serious infection usually stunts the plant and scars the roots making them unsalable.

   Since this fungus is related to water molds, it needs free water for reproduction. When susceptible seedlings are present in the soil, infection can be very rapid. The fungus overwinters in plant tissue as spores that are formed as the soil dries out. The optimum temperature for infection is 82-86°F.

   Control of this disease includes good soil drainage, crop rotation, and the use of treated seed.

3. Downy mildew can be found on the above ground parts of sugar beets. It is caused by the fungus Peronospora schachtii.

   When seedlings are infected, the cotyledons become pale, both sides are covered with fruiting bodies of the fungus and they tend to curl downward sharply. These seedlings usually die and provide a good source of inoculum for older plants in the field. The infested older plants form irregular pale green areas on the leaves' upper surface that correspond to the fruiting fungal layer on the lower surface. These areas later turn brown and die. Similar lesions may also be found on the bracts, branches, and flowers, causing plant distortion. Severely attacked plants are stunted and edible root parts develop very slowly.

   This fungus overwinters in seeds, the crown of seed roots, and discarded, diseased roots as either spores or mycelium. Infected seeds reproduce spores rapidly once they are planted. From here, the spores are splashed onto the remaining crop. A favorable environment, including free water, 33-35°F. temperature for spore germination, and 33-68°F. for infection, causes rapid fungus reproduction and spread.

   Control measures include crop rotation, soil drainage, use of disease-free seed, seed treatment, and the use of Bordeaux mixture on the leaves.

B. VIRUS DISEASES

1. Curly top virus of beets has caused such heavy losses that sugar beet factories have been abandoned in severely hit areas. The virus has a leafhopper vector, Circulifer tenellus, which has also been called the "whitefly". The leafhopper breeds on many different weed species (primarily gooseberry and those of the mustard family) and can transmit the virus from susceptible weed hosts. As rangeland dries up, the leafhopper moves into sugar beet fields, taking the virus with it.

   Infected sugar beet leaves curl upward and the leaf veins become roughened and distorted. The petiole is shortened and growth of the entire plant is retarded. Beet roots form large numbers of tiny side rootlets.

   The most effective control of this virus is the use of resistant varieties.

C. NEMATODE PESTS

1. Sugar beet nematode (Heterodera schachtii) is a minute whitish eelworm that can cause severe problems in infested sugar beet fields. It attacks plant roots, killing or stunting the plants. On hot days, infested plants usually wilt severely. The beet root is covered with short, hairy roots and the nematode cyst is obvious on these roots. Nematode infestation can weaken the plant, increasing susceptibility to other plant diseases. Severe infestation often causes young plants to die.

   The nematode overwinters in the soil as egg cysts. Egg hatch and the larvae enter the roots to feed. They go through three instars then the males leave the roots and the females remain attached. After the females are fertilized, they lay from one to six hundred eggs. One third of the eggs laid hatch immediately, repeating the feeding and reproductive stage.

The remaining two-thirds remain in the females body as cysts that can remain viable for as long as five years.

Long crop rotation (four-five years) with non-susceptible crops is the best control measure once a field is infested. It is important to restrict the spread by proper disposal of dump dirt and control of susceptible weeds (including mustard, knotweed, lambsquarters, ladysthumb, purslane, curly dock, and nightshade).

If a field is infested, it is possible to fumigate with Telone, D-D, Temik, or other registered nematicides.

CHAPTER X

DISEASES OF SUNFLOWERS

As sunflower production is gaining importance in Montana, it is necessary to recognize some of the major pest problems associated with it. There are ten commonly recognized diseases of sunflower that can occur in Montana.

1. Downy mildew is caused by the fungus Plasmopara halstedii. This disease is transmitted through infected seed, plant residue in the soil, and spores that can be blown great distances by the wind. The sunflower plants are prone to infection during or immediately after emergence and can be infected up to the flowering stage. Plants infected later seldom show systemic infection but may carry the fungus and produce infected seed.

   Symptoms include dwarfing and leaf discoloration. Plants infected after the four-leaf stage show root damage and are more susceptible to drought and lodging. The erect platform heads have little seed set. During periods of high humidity, white cottony masses of mycelium appear on the lower leaf surface. This fungus can persist five to ten years in soil and the spores can blow many miles.

   Controls include long-term crop rotation, destruction of volunteer and weed sunflower, field selection, and delayed planting. Resistant varieties are available and afford the best control measure.

2. Rust is caused by the fungus Puccinia helianthi. This disease is characterized by cinnamon-colored spots usually on the leaves, but with a severe infestation, also on the heads, stems, petioles, and bracts. As the season progresses, black overwintering spores replace the summer spores.

   Control of this disease includes destruction of volunteer and native sunflower plants that can be infected by spores produced early in the spring and planting resistant varieties.

3. Sclerotinia stalk and head rot is caused by the fungus Sclerotinia sclerotiorum. This disease attacks a wide variety of vegetable and field crops and sunflower is very susceptible.

   The sunflower plant is attacked any time from the seedling stage to maturity, and usually the first symptom of the disease is a sudden wilting of the leaves. Later, a canker will develop on the stalk from three to ten inches above the ground. This canker appears to be soft, grey to brown in color with a water soaked appearance. A dense white mold will form on the surface of the canker which will harden and turn black with age. The stem usually lodges at the location of this canker. Head rot usually occurs during periods of rainfall or high humidity.

   The fungus overwinters in the soil and may be spread by farm implements, animals, and contaminated seed. Irrigation also favors spread of this disease.

There are no known resistant varieties to this disease but losses may be minimized by planting pure seed, using long-term rotations (four or more years) with non-susceptible crops, and not over-fertilizing.

4. Verticillium wilt is caused by the fungus Verticillium dahliae. This disease is usually a problem on light soils where sunflower has been grown for several years. The symptoms include mottling of the leaves from the lower leaves upward. The leaves will soon dry out completely. This disease is persistent and once it is seen in a field, it will be present as long as susceptible crops are planted in the field.

   Control of this disease includes planting resistant varieties or disease-free seed and use of long-term rotations with non-susceptible crop.

5. Phoma blackstem is caused by the fungus Phoma oleracea. The symptoms appear as large brown lesions on the stems, but may also be seen on the petioles, leaves, and back of heads. It usually starts as large black patches at the petiole base on the stem and spreads. The attacked plant will be weak and form small heads with poor seed set. The plant may also lodge. The disease is associated with heavy rainfall at the time of flowering. There is no known control but field sanitation and crop rotation may be helpful.

6. Alternaria stem and leaf spot (Alternaria spp.) is a little known fungus disease. It is usually not prevalent until after flowering. The disease first appears as circular dark spots on the leaves with flecks, streaks, and lesions on the stem, petioles, and the back of the head. During periods of high temperature and humidity, the lesions will enlarge and cover the entire stem. A heavy infestation can result in defoliation and lodging. There are presently no known control measures.

7. Septoria leaf spot is a fungal disease caused by Septoria helianthi. Moderately high temperatures and frequent rainfall favor the development of this disease. Symptoms first appear as water-soaked grey spots with darker margins on the leaves. These spots usually develop after flowering and may merge, leaving roughly circular dead areas on the leaves. The disease progresses from the lower leaves to the upper ones. Some yield reduction may occur. In northern areas, conditions don't favor this disease until late in the season and infection is light with yield loss negligible.

8. Powdery mildew is caused by the fungus Ersiphe cichoracearum. This disease is found at the full-bloom stage and appears as white to grey-tan mildewed areas on the leaves. The infested areas on the leaves may merge until most of the plant surface is involved. Later on, the disease takes a dusty appearance with the presence of black dots. The lower leaves are usually infested more heavily than the upper leaves.

9. Charcoal rot is caused by the fungi Macrophomina phaseoli or Sclerotium bataticola. This disease is sporadic and unpredictable in the northern areas and is favored by high temperature and drought conditions. It causes poorly filled heads, premature ripening, and drying of stalks. Little effort has been made to control this disease due to its sporadic occurrence and low intensity.

10. Rhizopus head rot is caused by several species of Rhizopus. It is often found on heads damaged by birds, hail, or insects. It looks very much like Sclerotinia head rot but when closely examined, there are no sclerotia. It is found sporadically during warm, wet weather and is rarely a problem in northern areas.

CHAPTER XI

DISEASES OF RAPE AND MUSTARD

1. Staghead or white rust is a disease caused by the fungus Albugo candida. It forms green or brown blisters on stems and pods with white to cream colored pustules on the underside of infected leaves. It also causes swelling and deformation of terminal parts of flower stalks, turning them dry, hard, and brown as they mature ("stagheads"). The fungus overwinters as thick-walled resting spores either on seeds or in the soil. They infect the underside of seedlings early in the season and produce thin-walled, colorless sporagnia that cause secondary spread of the disease to more leaves as well as stems and pods. The staghead stage is caused by early infection of young flower buds.

   Rust races attack only certain members of the mustard family. Argentine type rape is immune and yellow mustard is resistant. Other rapes and mustards are fairly susceptible. Wild mustard (Brassica kaber) is often a reservoir for inoculum.

   At this time, the best control measures include the use of resistant varieties, destruction of volunteer turnip rape and wild mustard and proper seed cleaning. Crop rotation may be effective, but no one is sure just how long the resting spores will last in the soil. Some fungicides may be available in the future but there are none available at this time.

2. Sclerotinia sclerotiorum is a disease organism that infects a wide range of plants. Sclerotinia stalk rot of rape and mustard is similar to that found on sunflower. Lesions on the stem become soft and water girdling the entire stem and causing the plant to wilt and die. Infected plants tend to ripen prematurely and diseased tissue will shred off the plant.

   The fungus forms sclerotia which overwinter in the soil. These sclerotia germinate during June and July, generally coinciding with the flowering stage of the crop. The intensity of the disease, as well as yield reduction, varies from year to year. Early infection results in a reduction of seed set while a later infection may cause very little damage.

   This is a widespread fungus with an extensive host range. This, coupled with its survival ability in the soil, makes control difficult. Control of susceptible weeds and volunteer hosts and seed cleaning to remove sclerotia are the most effective controls now available. Cereals and grasses are immune to sclerotia stalk rot so long term rotations of greater than four years will also help control this disease.

3. Blackleg (Leptophaeria maculans) infects the leaves of rape and mustard forming dirty white, round to irregular shaped lesions. These lesions are dotted with small, black fruiting bodies (pycnidia). Later in the season, poorly defined white, grey, or black lesions can be found on the stems, often near the base of the plant. During periods of wet weather, pink spore masses are exuded. If the infection is severe, large portions of the stems may be cankered, eventually girdling the stem. Blackleg often causes premature ripening and shriveled seed production in the crop.

The fungus overwinters in infected stubble and spreads from early spring throughout the growing season. Spores are produced rapidly and are wind blown to nearby leaves. The disease is widespread on all crucifers. It is potentially a serious threat to rape and mustard production.

Destruction of infected residue helps control this disease. Rape or mustard should not be planted in stubble or adjacent to a field that was infected the previous year. The fungus is relatively short-lived and will not survive for more than two years in soil or residue so crop rotation is an effective control.

4. Downy mildew (Peronospora parasitica) causes a white, mealy growth on lower leaf surfaces, usually during periods of wet weather. The life cycle of downy mildew is similar to white rust and it is often found associated with it. It is only found sporadically under cool, moist conditions. Control is the same as for white rust.

5. Alternaria black spot is caused by the fungi Alternaria brassicae and A. raphani. Black or brown dots form on stems and pods and gradually develop into prominent spots or elongated lesions. Leaf spot color depends primarily on environmental conditions.

   The fungal spores overwinter on plant debris and weeds are wind blown onto the crop during the spring. Diseased seed can also be a primary source of inoculum. Secondary infection is from spores produced on leaf, stem, and pod spots. These fungi are found on many related weed species and can cause up to 20% reduction in crop yield.

   Control includes use of disease free seed, clean seed, crop rotation, and control of volunteer weed hosts. There are no recommended fungicidal treatments.

6. White leaf spot and grey stem often completely discolors a field by harvest but it usually infects the crop so late in the growing season that is rarely causes any serious yield reduction. The fungus (Pseudocercosporella capsellae) develops whitish spots on rape and mustard leaves in the summer. Late in the season, large, elongated purple or grey speckled patches appear on the stems and pods. The fungus overwinters on stubble and is wind blown to the crop. It has a wide host range among common weeds so weed control is an important control measure for white leaf spot. Crop rotation also aids in control.

7. There are several organisms that cause root and foot rots in rape and mustard including Rhizoctonia solani, Fusarium spp., and Pythium spp. Early spring infections can cause poor emergence or seedling blight, resulting in thin stands or reseeding of the crop. Later infections develop brown, hard, clearly defined lesions at the stem base and discoloration of the tap root. Infection can cause premature ripening of a single plant or a patch of plants. The fungi are generally soil-borne, but Fusarium can also be found on seeds. Control methods include crop rotation, use of clean, healthy seed, and early sowing in a firm seed bed.

8. Aster yellows, a mycoplasma disease, forms small round to oval, blue-green, hollow bladders in place of normal seed pods. It is spread by

leafhoppers that, once acquired, can transmit the mycoplasma for the rest of their life span. The prevalence of the disease depends on the abundance and timing of the leafhopper and is variable from year to year. The mycoplasma causes disease in a wide range of plants. There are no practical control measures as this disease is of minor importance on rape and mustard.

9. Brown girdling root rot appears as lesions on the taproot and at the base of the lateral roots. The cause of this disease is unknown. The lesions expand and coalesce and the roots below the girdling fall off. Plants ripen early, but if given enough moisture and protected from uprooting winds, they may still set seed. There are no chemical or cultural controls available but Argentine type rape has a field tolerance.

CHAPTER XII

DISEASES OF SAFFLOWER

1. *Alternaria leaf spot* (*Alternaria carthami*) is the most important disease of safflower in Montana. It develops most rapidly when there is an extended period of rain, heavy dews or fog in late July or August, when safflower is in bloom. The fungus produces large, white to brown, irregular shaped spots on leaves and flower bracts of the plants.

   Alternaria typically overwinters as mycelia in diseased plant refuse. The spores can be carried on or in the seed, thus causing seed rot or damping off. Primary infection results from seed transmission or from wind blown spores from other plants. The spores are spread within a field by wind, splashing rain, and implements.

   There are some seed treatments available for control of seed borne spores. Foliar treatment is an effective control and there are some leaf spot resistant safflower varieties available.

2. *Safflower rust*, caused by the fungus *Puccinia carthami*, occurs naturally in the same areas and under similar conditions to leaf spot. Spores are carried on the seed or in the soil. If young seedlings are attacked, stand loss may be extensive. The fungus also infects roots and crowns of the plant. Leaf and stem infections occur also and can cause severe losses. Dark red spores usually develop on the above ground parts of the plant and spread the disease to nearby plants throughout the growing season.

   There are some seed treatments available to control rust on seeds but these do not control the soil borne spores. The most practical control for soil borne inoculum is crop rotation. There has been some research for rust resistance in conjunction with leaf spot resistance.

3. Several soil fungi can cause root rot in safflower, the most damaging of which is *Phytophthora drechsleri*. This disease is most important after irrigation or in poorly drained dryland areas. The fungi cause fewer problems in dryland areas. Seedlings are rarely infected due to low temperatures. Infected plants dry up rapidly. There are some resistant varieties available.

APPENDIX I

PLANT PATHOLOGY GLOSSARY

acervulus (acervuli) - an open, saucer-shaped fruiting body bearing asexual spore

active resistance - resistance produced by galls as a result of their stimulation by the causal agent

aecium or aecidium (aecidia) - a cluster-cup or fruiting body developed in some of the life cycles of certain rust fungi

aeciospore or aecidiospore - spore borne in an aecium

aerobic - dependent upon free or uncombined oxygen for life

albinism - the white appearance of plant parts resulting from failure of chlorophyll production

anaerobic - not dependent upon free oxygen for life

annulus (annuli) - the ring on the stem of certain species of mushrooms

antheridium (antheridia) - the male gametangium

antibody - substance produced in the body in response to the parenterical introduction of an antigenic material; see antigen

antigen - any substance that, when introduced parenterally into the animal tissues, stimulates the production of an antibody and, when mixed with that antibody, reacts with it in some observable way; see antibody

apothecium (apothecia) - an open, saucer-shaped, disc-like sexual fruiting body bearing asci, characteristic of the discomycetes; see perithecium

appresorium - a swelling or enlargement of the germ tube that functions as an organ of attachemnt during penetration of the host

ascocarp - a fruiting body producing asci, including peritecia and apothecia

ascogonium (ascogonia) - the female gametangium of the ascomycetes

ascospore - spores borne in an ascus

ascus (asci) - a sack-like structure in which sexual spores (ascospores) occur, usually eight in number; characteristic of ascomycetes

aseptate - lacking cross walls

asexual - without sex; reproduction without gametes

atrophy - a lack of development in certain plant parts or tissues as a result of subnormal cell division or enlargement autoecious - all of the spore forms or fruiting structures are produced on one host

avirulence - characteristics of a pathogen rendering it unable to parasitize a given host

bacterium (bacteria) - a microscopic, unicellular plant, lacking chlorophyll and reproducing by division of the body into two parts, fission

basidiocarp - a fruiting body that bears basidia

basidiospore - small spores borne on a basidium; see also sporidium

basidium (basidia) - a club-shaped structure or stalk bearing the basidiospores, often called promycelium in the smuts and rusts

blast - sudden death of young buds, inflorescences, or young fruits

blight - the rapid discoloration and death of tissues over certain portions of plants

blotch - superficial discoloration of plant parts in which a slight necrotic injury of the epidermal tissues is usually emphasized by the presence of dark mycelium or fruiting structures of the fungus pathogen

canker - a dead area on a stem surrounded by living cortical tissues

carrier - a plant that carries a virus or other infective agent without showing symptoms

chlamydospore - thick-walled asexual spores may also form within mycelium; also applied to the spores produced by smuts; formed by a modification of certain hyphal cells

chlorosis - the yellowish-white or gray conditions of plant parts resulting from the destruction of chlorophyll

clamp connection - a bridge-like hyphal connection between two cells of a hypha, formed by many basidiomycetes

cleistothecium (cleistothecia) - a completely closed ascocarp

coencytic - nonseptate; a multinucleate mass of protoplasm formed by division of the nucleus but not of the cytoplasm of an original cell with a single nucleus

conidiophore - a stalk bearing conidia

conidium (conidia) - an asexual spore usually produced at the tip or side of a hypha

conk - large, woody, spore-bearing sporophore of the basidiomycetes; a wood-rotting fungus

context - the fibrous tissue that composes the body of the pileus in the basidiomycetes curl - the distortion, fluting, and puffing of a leaf resulting from the uneven development of its two sides

cystidium (cystidia) - a large, sterile, club-shaped structure in the hymenium of basidiomycetes

damping-off - the rapid wilting and rotting of seedlings or cutting; usually caused by seed or soil-borne fungi

degeneration - a gradual disappearance, or catabolic modification, or normal structure of the cells

diploid - the 2n number of chromosomes

direct necrosis - the rapid and complete death or disintegration of the tissues as the causal agent advances in the host

disease - deviation from normal functioning of a plant physiological process, of sufficient duration or intensity to cause disturbance or cessation of vital activity; brought about by parasitic organisms or unfavorable environment and interfering with plant structure, function, and/or economic value

dwarfing - the underdevelopment of any organ of a plant

echinulate - spiny

egg - the female gamete

endemic - more or less constantly present from year to year

endogenous - produced inside; see exogenous

epidemic - the widespread and destructive development of a disease on many people in a community or communities; see epiphytotic

epinasty - bending outward or drooping downward of a plant part, often terminal growth of a plant, leaf or petiole; usually more rapid growth of the upper side of an organ

epiphytotic - the widespread and destructive development of a disease on many plants in a community or communities; see epidemic

etiolated - yellowed as a result of insufficient light

etiology - that phase in the study of a disease which deals with the causal factors, together with the relations of the causal factor to the host

excresence - an outgrowth of abnormal character from the surface of a diseased organ

exogenous - produced outside; see endogenous

exudations - liquids discharged from the protoplasts facultative parasites - organisms that are ordinarily saprophytic but under certain conditions may become parasitic

facultative saprophytes - organisms that usually live as parasites but under certain conditions are capable of saprophytic growth

fasciated - broadened and flattened

flagellum (flagella) or cilium (cilia) - a whip-like structure that projects from free cells, such as bacteria and zoospores, and that functions as an organ of locomotion

flagging - the loss of turgor and the drooping of plant parts, usually following a water deficit; dead, brown pine branches are also referred to as flags

form - a subdivision within a species or variety; see race

fruiting body - a structure bearing spores

fungicide - a chemical that inhibits or kill fungi

fungus (fungi) - a plant not differentiated into root, stem, and leaf; devoid of chlorophyll

gall - an overgrowth induced by an infectious entity that stimulates the localized formation of imperfectly vascularized masses of abnormal cells

gametangium (gametangia) - a structure that produces gametes

gamete - a sex cell or sex nucleus that fuses with another in sexual reproduction

general necrosis - the rapid and complete death or disintegration of the tissues as the causal agent advances in the host

genus (genera) - a subdivision of the plant or animal kingdom containing species

germ-tube - the hypha developed by a spore upon germination; by growth and branching a germ-tube usually develops into the mycelium

giant cells - large, usually multinucleate cells formed by abnormal cell fusions or failure of proper cell wall formation following growth and nuclear division

hairy root - the development of large numbers of small roots on a limited area

haploid - the 1n number of chromosomes

haustorium (haustoria) - a special mycelial organ that usually develops within the host cell and absorbs nutrients

heteroecious - applying to the condition in which the spore forms or fruiting structures must be formed on more than one host to complete the life cycle of the pathogen, as in the rusts

heterokaryotic - containing nuclei of different strains heterothallic - a fungus that is self-sterile and requires the union of two compatible strains for sexual reproduction; see homothallic

homothallic - a fungus that is self-compatible; sexual reproduction takes place in a single individual; see heterothallic

host or suspect - the plant or animal upon which a parasite lives

hyaline - clear, translucent

hymenium - a layer consisting of asci or basidia

hyperplasia - an abnormal development of tissues due to an increase in the number of cells

hypertrophy - an abnormal development of tissues due to an increase in the size of individual cells

hypha (hyphae) - the mycelial-like threads or vegetative growth of a fungus

hypoplasia - subnormal number of cells

immunity - exemption from infection

incitant - agent that causes the disease under the influence of other factors; same as causal organism

incubation period - the period between the time the inoculum is introduced on or in the host and the time infection is evident

indirect necrosis - the delayed death of the tissues that follows the advance of the pathogen in the host

infection - the process of gaining entrance and becoming established as a parasite

infection court - that place on or in a plant where the inoculum will be able to establish pathologic relations

inoculation - the process of transferring inoculum to the infection court on or in the host

inoculum - that portion of a pathogen which in transferred to a host; usually consists of spores, bacteria, mycelial fragments, nematode cysts, or virus particles

intercellular - occurring between cells

intracellular - occurring within cells

intravascular - occurring within the vascular bundles

knot - an imperfectly vascularized, knob-like overgrowth on roots or stems; sometimes used to describe a small gall

lesion - a localized diseased area

life history (life cycle) - the succession of developmental stages in the life of an organism

local invasion - invasion involving only a localized area of the plant; see systemic invasion

local necrosis - the death or disintegration of cells and tissues in a localized area of an organ

macroconidia - relatively large conidia

macroscopic - that which may be seed with the unaided eye, or without the aid of a microscope

medium (media)-a nutrient substrate employed in laboratories for growing microorganisms

microconidia - extremely small conidia

micron - a millionth of a meter; one thousandth of a millimeter; approximately 1/25,000 of an inch

mosaid - a disarrangement of the chlorophyll content of tissues causing the green and yellow areas to form variegated patterns

mummification - the drying down and shriveling of fruits and other plant parts

mycelium - the vegetative structure of a fungus, made up of filamentous hyphae

mycoplasma - a microscopic organism, sized between viruses and bacteria, lacking a cell wall; some can cause plant diseases

necrosis - the death or disintegration of cells and tissues

nematodes - round-, thread-, or eel-worms; phylum of animals not closely related to any other; includes free-living forms as well as plant and animal parasites; long, cylindrical, unsegmented bodies with a heavy cuticle

non-infectious disease - a disease caused by environmental factors, not by a pathogen

obligate parasite - organisms that can live only as parasites

obligate saprophyte - organisms that can live only as saprobes

oogonium (oogonia) - the female gametangium containing one or more eggs

oospore - a sexual spore produced in an oogonium, formed by the union of male and female gametes

ostiole - the pore or opening of an ascocarp or pycnidium

paraphysis (paraphyses) - a sterile, hair-like structure in a hymenium

parasite - an organism that lives in or upon some living plant or animal from which it receives part or all of its food materials passive resistance - resistance resulting from qualities in the host prior to the attack by the causal agent

pathogen - a disease-producing organism

pathogenesis - that pahse of life cycle of a pathogen during which it becomes and remains associated with the living tissue of its host

pathogenicity - ability of an organism to cuase disease

perennial mycelium - a mycelium which persists in a host plant from one season to the next

peridium (peridia) - the outside wall of a fructification

perithecium (perithecia) - a spherical or flask-shaped, ostiolate, sexual fruiting body that produces asci

phytotoxic - poisonous or damaging to plants

pileus (pilei) - upper portion or cap of certain types of fructification of basidiomycetes and ascomycetes

plasmodium (plasmodia) a naked multinucleate mass of protoplams

primary infection - the infection instituted by the pathogen after a period of rest, usually in the spring

promycelium (promycelia) - the short hyphal filament or basidium produced by the germinating resting spores (chlamydospores) of the smuts or the teliospores of the rusts

pustule - a local elevation of the epidermis that may rupture to expose the causal agent

pycnidiospore - a conidium borne in a pycnidium

pycnidium - a globose asexual fruiting body containing conidia

pycnium (pycnia) - see spermagoinium

race (physiologic race) - a name given to a subdivision of fungi within a species. Races within a species differ qualitatively in their ability to infect certain hosts, but show little, if any, difference morphologically.

resistance - the sum of the qualities of the host and causal agent that retard the activities of the causal agent

resupinate - lying flat on the substrate

reticulate - netted

rhizomorph - a thick, root-like structure composed of hyphae rosetting - failure of the internodes of shoot or branch to elongate normally, causing the foliage to be crowded into a cluster

rot -state of decomposition and putrification

russeting - brownish, superficial roughening of the epidermis of fruit, leaves, tubers, or other organs

saprogenesis - that phase in the life history of an organism when it is not in direct contact with a living host

saprophyte - an organism growing on dead organic matter

scab - the abnormal thickening of the outer layer or layers of tissues resulting from local irritation

scald - a blanched appearance of plant parts

sclerotium (sclerotia) - a hard, dense, compact mass of mycelium with a specialized outer coat or rind

secondary infections - those infections initiated by a pathogen from primary or other secondary infections, without an interposed resting or dormant period

septate - divided by cross walls

seta (setae) - a bristle-like hair

sign - the manifestation of disease by the presence of structures of the causal agent; see symptoms

somatic - the vegetative phase

sorus (sori) - a cluster of sporangia or spores usually covered at first by the epidermis of the host

species - a subdivision of a genus; a collection of plants which is so marked and so homogenous that it can be conveniently designated as one thing

spermagonium (spermagonia) or pycnium (pycnia) - a flask-shaped, lens-shaped, or conical fruiting body producing haploid (+ or -) spores (spermatia or pycniospores)

spermatium (spermatia) or pycniospore - a haploid spore (+ or -) borne in a spermagonium

sporangiophore - a structure that bears sporangia

spore - a reproductive body composed of one or more cells and capable of reproducing the organism

sporidium (sporidia) or basiodiospore - a small spore produced by basidia

sporodochium - a densely packed group of short conidiophores sporophore - a fungus structure producing spores

sterigma (sterigmata) a small stalk on a basidium on which a basidiospore is borne

sterile - failure to reproduce; or free from living organisms

strain - a subdivision within a species or variety that differs quantitatively from other forms of the same organism

streak - an elongated lesion with irregular sides; see stripe

stripe - an elongated, narrow lesion with parallel sides; see streak

stroma (stromata) - a cushion-like, mycelial mass of tissue on or in which fructification usually occurs

susceptibility - the sum of the qualities of a plant and causal agent that allows the development of the causal agent

swarmspore or zoospore - a motile, naked spore

symptoms - disease responses presented by the plant itself

syndrome - a collection of symptoms with respect to a specific disease

synnema (synnemata) - a group of tall conidiophores tightly placed together, forming an elongated spore-bearing structure

sytemic infection - a type of infection involving the entire plant; pathogen spreads within the plant from point of inoculation

teliospore or teleutospore - a thick-walled resting or overwintering spore, produced by rust and smut fungi

tolerance - ability of the plant to endure the development of the parasite without showing marked symptoms of disease or injury; usually causes a yield reduction

urediospore - binucleate repeating spore produced by certain rust fungi

uredium - a cluster or urediospores

variety - a subdivision within a species

vector - an agent, such as an insect, that may transmit a virus or other pathogen

vein-clearing - the disappearance of green color along the veins

virulence - characteristics of a pathogen enabling it to parasitize a given host

viruliferous - capable of transmitting a virus

virus - a minute, infectious nucleo-protein that causes disease

volva (volvae) - a cup at the base of certain mushrooms wilt - the loss of turgescence of plant tissues, usually as a result of inadequate water supply

witches' broom - a broom-like overgrowth produced by the dense clustering of branches

yellowing - the yellow color of plant parts resulting from the excessive proportion of yellow pigments produced by the underdevelopment or partial destruction of the green pigments

zoospores or swarmspores - motile spores provided with one or more flagella

zygospore - a thick-walled sexual spore, formed from the union of two gametangia

zygote - a diploid cell resulting from the union of two haploid cells

APPENDIX II

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